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Los Angeles County Sanitation District, Whittier, Calif

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16 ABSTRACT

A 3.17 l/sec(50 gpm)pilot plant evaluation of the independent physical-chemical treatment (IPC)process was conducted for 27-months at Pomona, California. The pilot plant consisted of chemical clarification w/alum at 25 mg/l as Al and an anionic polymer at 0.3 mg/l followed by a single-stage, pressurized downflow carbon column operated at a hydraulic loading of 2.71 l/sec/m^2(4 gpm/ft^2)and an empty-bed contact time of 30 min. Performance data obtained have demonstrated the stability of the IPC system in producing effluent of excellent overall quality. The suspended solids, total COD and total phosphate removals in the IPC system were 96.6%, 94%, & 92%, respectively. In the course of the study, several methods of controlling sulfide generation in the carbon column were evaluated. Continuous sodium nitrate addition to the carbon column at an average dosage of 5.4 mg/l N was found most effective in preventing sulfide generation. The addition of nitrate had another favorable effect in that it permitted, through enhancement of biological activity, a very high organic loading on the carbon column. The carbon capacity was 3.54 Kg total COD removed/Kg carbon and 1.54 Kg dissolved COD removed/Kg carbon. Although regeneration was not necessary, it was conducted in an effort to obtain data on the effects of repeated regenerations on the carbon characteristics. In all respects, the regenerations were as successful as those conducted on granular activated carbon used in the tertiary treatment mode. The performance of the regenerated carbon was found equal to or slightly better than that of the virgin carbon. Carbon loss averaged 4.5% per regeneration.

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INDEPENDENT PHYSICAL-CHEMICAL TREATMENT OF RAW SEWAGE

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problems, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Independent physical-chemical treatment of municipal wastewater is an alternative technology to biological treatment for achieving secondary effluent standards. This report summarizes a successful long-term pilot plant investigation of one mode of this new concept in wastewater treatment.

Francis T. Mayo
Director, Municipal Environmental
Research Laboratory

ABSTRACT

A 3.17 l/sec (50 gpm) pilot plant evaluation of the independent physical-chemical treatment (IPC) process was conducted for 27 months at Pomona, California under the auspices of the U.S. Environmental Protection Agency and the Los Angeles County Sanitation Districts. The pilot plant consisted of chemical clarification with alum at 25 mg/l as Al and an anionic polymer at 0.3 mg/l followed by a single-stage, pressurized down-flow carbon column operated at a hydraulic loading of 2.71 l/sec/m^2 (4 gpm/ft^2) and an empty-bed contact time of 30 minutes. The main objectives of the study were to evaluate various methods of controlling sulfide generation in the carbon column and to determine the effects of repeated thermal regeneration cycles on the adsorption capacity, carbon loss, pressure buildup of IPC carbon.

Performance data obtained have demonstrated the stability of the IPC system in producing effluent of excellent overall quality. The suspended solids, total COD and total phosphate removals in the IPC system were 96.6%, 94%, and 92%, respectively.

In the course of the study, several methods of controlling sulfide generation in the carbon column, such as oxygenation, chlorination, and sodium nitrate addition, were evaluated. Of the methods evaluated, continuous sodium nitrate addition to the carbon column at an average dosage of 5.4 mg/l N was found most effective in preventing sulfide generation.

The addition of nitrate had another favorable effect in that it permitted, through enhancement of biological activity, a very high organic loading on the carbon column. At the end of the first cycle, the carbon capacity was 3.54 Kg total COD removed/Kg carbon and 1.54 Kg dissolved COD removed/Kg carbon.

Although regeneration was not necessary, it was conducted in an effort to obtain data on the effects of repeated regenerations on the carbon characteristics. These were the first large-scale regenerations of granular activated carbon used in the IPC mode. In all respects, the regenerations were as successful as those conducted on granular activated carbon used in the tertiary treatment mode. The performance of the regenerated carbon was found equal to or slightly better than that of the virgin carbon.

This report was submitted in fulfillment of Contract No. 14-12-130 by the Los Angeles County Sanitation Districts, Whittier, California under sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 1973 to August 1975.

CONTENTS

Disclaimer ii

Foreword iii

Abstract iv

Figures viii

Tables x

Acknowledgements xii

1. Introduction 1

   Background of the study 2

2. Conclusions 3

3. Recommendations 6

4. Experimental Program 7

   Pilot plant description and operation 7
   Sampling and testing program 16

5. Experimental Results 18

   Chemical treatment phase 18
   Carbon treatment phase 39
   Carbon regeneration results 71
   Discussion of system performance 83

6. Economic Analysis 97

   Chemical treatment costs 97
   Carbon treatment costs 102
   IPC system costs 102

References 108

FIGURES

Number		Page
1	Schematic diagram of the IPC pilot plant	8
2	Carbon contactor detail	10
3	Detail of the carbon column underdrain system	12
4	Cross sectional view of the multiple hearth furnace	13
5	Schematic diagram of the air pollution control system	15
6	Hourly variation in suspended solids concentration	20
7	Variation in suspended solids concentration and alum dose	22
8	Suspended solids removal patterns in the IPC system - first cycle	24
9	Suspended solids removal patterns in the IPC system - second cycle	27
10	Suspended solids removal patterns in the IPC system - third cycle	28
11	Zone settling velocity as a function of suspended solids concentration	30
12	Batch flux curves of IPC sludge with and without polymer	31
13	Batch flux curve with polymer	32
14	Effect of cycle time on filter yield and cake solids	34
15	Performance of various chemical conditioning agents at 2 minutes cycle time	35
16	Performance of various chemical conditioning agents at 4 minutes cycle time	36

FIGURES(CONTINUED)

Number		Page
17	Effect of chemical dosage on filtrate quality	37
18	Variation in the carbon effluent total sulfide concentration	42
19	Effect of nitrate feed disruption on sulfide production	47
20	Surface wash-water backwash schedule	50
21	Air-water backwash schedule	51
22	Carbon column suspended solids loading and pressure drop - first cycle	53
23	Carbon column suspended solids loading and pressure drop - second cycle	56
24	Carbon column suspended solids loading and pressure drop - third cycle	57
25	COD removal through the carbon column - first cycle	59
26	COD removal through the carbon column - second cycle	63
27	COD removal through the carbon column - third cycle	65
28	Effect of regeneration on DCOD removal capacity	67
29	Effect of regeneration on per cent DCOD removal	68
30	DCOD profile through the carbon column	70
31	Turbidity and color removal through the carbon column - first cycle	72
32	Turbidity and color removal through the carbon column - second cycle	75
33	Turbidity and color removal through the carbon column - third cycle	76
34	Effect of copper waste on COD removal	88
35	Effect of copper waste on suspended solids removal	89
36	Effect of copper waste on turbidity removal	90
37	Proposed IPC system flow sheet	100

TABLES

Number		Page
1	Virgin Carbon Characteristics	11
2	Summary of Chemical Clarification System Performance with Ferric Chloride	19
3	Summary of Chemical Treatment System Performance with Alum and Polymer	23
4	Leaf Filter Test Results	38
5	H_2S Control Measures in the Carbon Column	40
6	Performance of the Various H_2S Control Measures	48
7	Carbon Capacity in IPC Plants	69
8	Carbon Column Performance	77
9	Effect of Regeneration on the IPC Carbon Characteristics	79
10	Furnace Operating Conditions during IPC Carbon Regeneration	81
11	Summary of Air Pollution Control System Performance	84
12	Summary of IPC System Performance	86
13	Heavy Metal Analyses	91
14	Mineral and Miscellaneous Analyses	92
15	Heavy Metal Constituents of Quench Water and Carbon Samples	94
16	Nitrogen Removal in the IPC System	95
17	IPC System Design Data	98
18	Unit Costs for Operation and Maintenance Estimate	99

TABLES(CONTINUED)

Number		Page
19	Estimated Chemical Treatment Costs	101
20	Estimated Granular Activated Carbon Treatment Costs	103
21	Estimated IPC System Costs	104

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The untiring efforts and assistance of both the laboratory and the pilot plant operating personnel of the Pomona Advanced Waste Treatment Research Facility are gratefully acknowledged.

SECTION 1

INTRODUCTION

The application of granular activated carbon in wastewater treatment technology has been greatly explored during the past ten years. This widespread use of the carbon has been attributed to the successful development of economical methods of regenerating the exhausted carbon. The large-scale use of granular activated carbon in wastewater treatment, however, has been primarily confined to the so-called tertiary treatment approach, in which the carbon treatment phase follows the conventional biological secondary treatment. In this treatment approach, there are inherent benefits achieved: lower organic load to the carbon bed thus allowing either higher effluent quality or shorter contact time; lower influent suspended solids, thus reducing the headloss through the carbon bed and obviating problems related to physical plugging, ash buildup and eventual accelerated loss of the adsorptive capacity of the carbon after repeated thermal regeneration cycles; and finally, lower supply of bacterial nutrients in the feed to the carbon column, thus reducing problems associated with abundant biological growth, septicity and possible hydrogen sulfide generation.

The other carbon treatment approach which has gained widespread interest in recent years is the independent physical-chemical treatment (IPC) of municipal and industrial wastewaters, in which chemically clarified raw sewage or primary effluent, with or without prior inert media filtration, is applied to the carbon column. This carbon treatment approach attempts to maximize the use of the granular activated carbon by including in its function not only the removal of refractory dissolved and biodegradable organic materials but also the use of the column as a deep bed filter for the removal of suspended and colloidal solids. Consequently, the carbon bed is loaded as heavily as possible within the limits of desired effluent quality. The IPC approach thus seeks to supplant conventional biological treatment processes. In this respect, the IPC process inherently offers several major advantages over conventional biological treatment systems, namely, IPC is practically immune to upsets due to materials toxic to biological systems, such as heavy metals from industrial waste discharges; it is more readily adaptable to rapid changes in influent flow and wastewater composition; it has lower space requirements; and finally, the IPC process can remove a significant amount of heavy metals.

BACKGROUND OF THE STUDY

In recent years, there have been several IPC pilot plant studies conducted by various investigators (1,2,3). Although these studies have indicated that IPC system can achieve excellent wastewater treatment, none was conducted for an extended period of time. Thus, operational problems such as sulfide generation, excessive column headloss and deterioration of carbon properties which can only become manifest with time, were not thoroughly investigated. In addition, at none of these installations was carbon regeneration practiced. While the technology for carbon regeneration in a multiple hearth furnace has been well developed and demonstrated for granular activated carbon used after biological treatment (tertiary treatment mode), it has not yet been applied for granular activated carbon used in the IPC mode. Therefore, this study was conducted to evaluate the performance over an extended period of time of an IPC system which includes regeneration of the granular activated carbon.

The specific objectives of the study were: To evaluate the performance of the chemical clarification system using alum and polymer; to demonstrate on a long-term basis, the effectiveness of granular activated carbon in the removal of soluble organic matter from chemically clarified raw sewage; to evaluate methods of controlling hydrogen sulfide generation in the carbon column; to determine the effects of repeated thermal regenerations on the carbon characteristics and performance, and finally to develop the cost estimates for the IPC system.

SECTION 2

CONCLUSIONS

1. The IPC pilot plant, consisting of a 3.78 l/sec (60 gpm) chemical clarification system followed by a 3.16 l/sec (50 gpm) single-stage, packed-bed, downflow granular activated carbon column, was operated successfully for 27 months. Extensive operating data collected during the field evaluation had demonstrated the capability of the IPC system in consistently producing effluents of excellent overall quality. The average carbon effluent TCOD, DCOD, suspended solids, turbidity and color were 19.3 mg/l, 13.5 mg/l, 6.7 mg/l, 6.3 JTU and 7.8, respectively.

2. During the virgin adsorption cycle, the carbon capacity was 3.54 Kg TCOD removed/Kg carbon and 1.54 Kg DCOD removed/Kg carbon. The corresponding carbon dosage was 0.021 Kg carbon/m^3 (173 lbs carbon/mil. gal). The DCOD removal efficiency did not change appreciably in the course of the virgin run, during which time 113,550 m^3 (30 million gallons) of chemically clarified raw sewage was processed through the column.

3. The organic removal through the carbon column during the entire study averaged 79.9 percent for TCOD, 72.2 percent for the DCOD and 78.5 for BOD_5. The DCOD removal efficiency through the carbon column increased following sodium nitrate addition to the carbon column as a result of enhancement of biological activity. The DCOD removal efficiency of the regenerated carbon was higher than that of the virgin carbon. The carbon capacity of the twice-regenerated carbon was slightly less than that of the once-regenerated carbon.

4. Analyses of metals on carbon prior to and after the first regeneration indicated that some of the metals which were removed from the sewage were not removed during regeneration. However, most of the metals removed by the carbon did not remain on the carbon but were carried out of the furnace with the flue gases. Dust collected from the bagnouse contained high levels of Ca, Cd, Cu, Cr, Al, Fe, Sn, Pb, Ni and Zn. Some of these came from corrosion in the carbon column rather than from the sewage.

5. An evaluation of the carbon characteristics following repeated thermal regenerations showed that after three regenerations, the iodine number and methylene blue number decreased about 26 and 5 percent, respectively. During the same period, the molasses number increased about 3.6 percent. The ash content of the carbon increased about 67 percent from

a virgin level of 6.4 to 10.7 percent after the first regeneration. On the second regeneration, only a slight increase in ash content was observed while a decrease was noted in the third regeneration.

6. The carbon regeneration loss ranged from 2.5 to 6 percent with an overall average of 4.3 percent for the three regenerations.

7. Of the various methods of sulfide control evaluated-namely, oxygen addition, chlorination, air-water backwash and sodium nitrate addition, continuous sodium nitrate addition to the carbon column at an average dosage of 5.4 mg/l N was found most effective in inhibiting sulfide generation in the carbon column.

8. The level of sodium nitrate required is a function of the organic concentration in the feed to the carbon column. The level required at Pomona to prevent sulfides is specific for the wastewater, and should not be directly transferred to any other situation. A rough rule of thumb is that the nitrate should be about 15 percent of the DCOD in the feed to the carbon column.

9. The carbon column, which served both as deep bed filter and an adsorber, was routinely backwashed on a daily basis with a volume of secondary effluent equivalent to 7 percent of the product water. The net headloss through the column during the daily backwash cycle varied considerably during the study. The weekly average net headloss varied from 0.11 Kg/cm^2 (1.6 psi) to 3.1 Kg/cm^2 (44 psi). The net headloss was equal to or less than 1.76 Kg/cm^2 (25 psi) 50 percent of the time.

10. The bulk of the pollutant removal in the IPC system was accomplished during the chemical clarification phase. Chemical clarification using alum at an average dosage of 25 mg/l Al (275 mg/l alum) with 0.3 mg/l of anionic polymer (Calgon WT-3000) was very effective throughout the study in producing good quality clarified effluent from raw sewage. The clarified effluent had an average turbidity, suspended solids and TCOD concentrations of 22.2 JTU, 28.3 mg/l and 95.8 mg/l, respectively. The total phosphate in the raw sewage, which had averaged 11.1 mg/l P, was reduced by 88 percent, resulting in a clarified effluent with total phosphate concentration of 1.3 mg/l P.

11. Results of bench-scale sludge studies performed in the course of the study showed that the alum-sewage produced was difficult to dewater. Chemical conditioning at a cost of $15-$17 per ton dry solids was required to achieve a yield of 4.9-9.8 Kg/m^2-hr (1-2 lb/ft^2-hr) with cake solids of 18 percent.

12. The total treatment cost for a 37,850 cu m/day (10 mgd) IPC system designed to produce a product water with an average TCOD of 25 mg/l, DCOD of 16 mg/l and suspended solids of 8 mg/l using alum and polymer, is estimated at 8.69¢/m^3 (32.57¢/1000 gallons). The estimated cost is based

on using an 8 x 30 mesh granular activated carbon with carbon dosage of 0.03 kg/m³ (250 lb/mil. gal) and a carbon regeneration loss of 5 percent per cycle. If regeneration were not required the cost is reduced to 7.92¢/m³ (29.68¢/1000 gallons). These cost estimates are representative of price levels as of March 1976, with an EPA sewage treatment plant construction cost index of 232.1.

SECTION 3

RECOMMENDATIONS

1. The results of the pilot plant study presented in this report indicate that the granular activated carbon column performance in the first adsorption cycle remained virtually unchanged throughout the 18.5 months of operation. Although not necessary, the column was regenerated to obtain data on the effects of repeated thermal regenerations on the IPC carbon column performance. It is recommended to conduct a long-term evaluation of the IPC carbon column without regeneration to determine the ultimate COD removal capacity.

2. Further studies should be carried out to determine the mechanism by which the biological activity on the carbon column allowed significantly higher carbon capacity. In this connection, attempts should be made to determine the cause of the apparently higher COD removal capacity of the regenerated carbon compared to virgin carbon.

SECTION 4

EXPERIMENTAL PROGRAM

PILOT PLANT DESCRIPTION AND OPERATION

Figure 1 shows the process flow sheet of the IPC pilot plant. The pilot plant consisted of a 3.78 l/sec (60 gpm) chemical clarification system followed by a 3.15 l/sec (50 gpm) single-stage, packed-bed, granular activated carbon column operated in downflow mode. A carbon regeneration facility complete with an air pollution control system was available in the pilot plant site. The details of the design and operation of the various components of the pilot plant are discussed in subsequent sections.

Chemical Treatment System

The chemical treatment system consisted of a rapid mixing unit 0.76m square (2.5 ft. square) with 1.07m (3.5 ft.) liquid depth followed by a three-compartment flocculation unit 1.37m (4.5 ft.) wide and 4.11m (13.5 ft.) long with 1.67m (5.5 ft.) liquid depth equipped with three variable speed paddle-type flocculators. The raw sewage was pumped at a constant rate of 3.78 l/sec (60 gpm) into a rectangular stilling tank provided with a V-notch weir for flow measurement. The chemical coagulant, either alum or ferric chloride, was fed directly to the rapid mixing unit by means of three timer-controlled positive displacement chemical pumps paced in such a way as to approximately match the incoming suspended solids concentration. The diurnal variations of the raw sewage suspended solids concentration was previously established by the analysis of hourly samples collected over several 24 hour periods. This feeding pattern was periodically checked during the course of the study by routinely analyzing for suspended solids, six four-hour composite samples of raw sewage and clarified effluent. An anionic polymer (Calgon WT-3000) was added as a coagulant aid at an average dosage of 0.3 mg/l. The polymer addition was confined to only 12 hours per day, from 11 a.m. to 11 p.m. to coincide with the period of high coagulant dosage. After 2.8 minutes of rapid mixing at 140 rpm, the sewage flowed into the flocculation unit where slow stirring for 42.5 minutes theoretical detention time was provided. The flocculation was operated at a velocity gradient, G of about 54 seconds^{-1}. The G value was obtained by calculation assuming a drag coefficient of 1.5 and a water velocity equal to 3/4 of the radial velocity at the center of the wooden paddles. The G value for rapid mixing was not estimated since an auxiliary air mixing was also used.

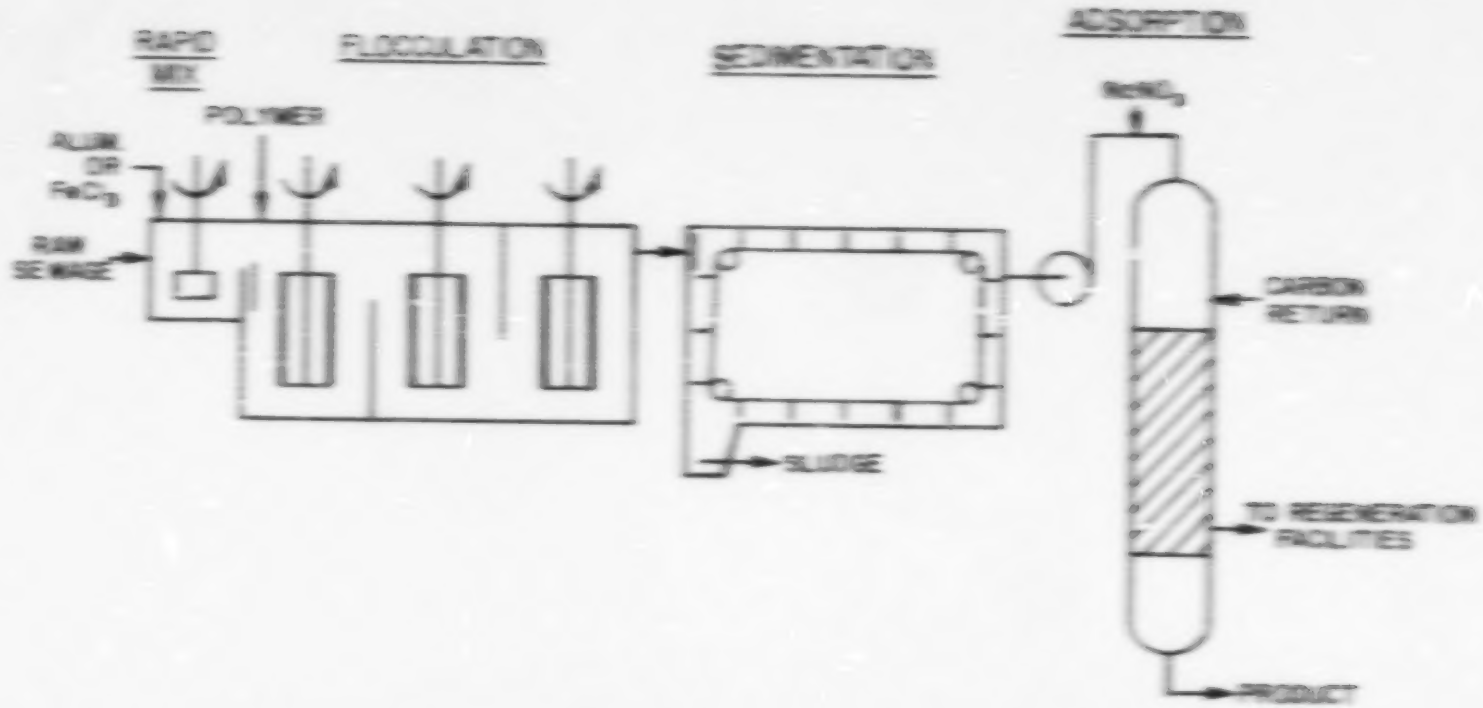


Figure 1. Schematic diagram of the IPC pilot plant.

The chemically coagulated raw sewage flowed into a rectangular clarifier where it was settled for a theoretical detention time of 84 minutes. At the flow rate of 3.78 l/sec (60 gpm), the clarifier overflow rate and weir rate, were respectively, 48 cu m/day/m^2 (1180 gpd/ft^2) and 2.06 l/sec/m (10 gpm/ft). The clarified effluent flowed by gravity to a 1.89-cu m (500-gallon) surge tank from which 3.15 l/sec (50 gpm) was pumped continuously to the carbon column. The clarified effluent tank was provided with an overflow and a low level cut-off switch for pump protection. The chemical sludge was pumped continuously from the clarifier sludge hopper at a constant rate of 0.17 l/sec (2.8 gpm) during the first 14 months of the study. Thereafter, the chemical sludge pump operation was placed on a timer control to withdraw sludge at 0.17 l/sec (2.8 gpm) for 15 minutes every hour. The intermittent sludge withdrawal was initiated in an effort to obtain more concentrated sludge.

Carbon Treatment System

The carbon column, shown in detail in Figure 2, was 1.22m (4 ft) diameter by 9.45m (31 ft) high and was designed for a working pressure of 3.52 Kg/cm^2 (50 psi). The interior of the column was coated with three coats of 8 mills each of Koppers Bitumastic 300 M coal tar epoxy to inhibit corrosion. The column contained 2360 Kg (5200 lbs.) of Calgon Filtrasorb 300 (8 x 30 mesh granular activated carbon) having virgin characteristics shown in Table 1. The 4.8/m (16 ft) deep carbon bed was supported by 20.32 cm (8 in) layer of graded gravel placed over Leopold filter blocks. Figure 3 shows the detail of the column underdrain system.

The chemically clarified raw sewage entered the top of the column through a 10.16 cm (4 in) pvc pipe. Throughout the study, the column was operated in a downflow mode at a constant flow rate of 3.15 l/sec (50 gpm) thereby providing a hydraulic loading of 2.71 l/sec/m^2 (4 gpm/ft^2) and an empty-bed contact time of 30 minutes. The column influent discharge outlet was located about 3.66m (12 ft) above the top of the carbon bed, thereby providing a capability of as much as 75 percent bed expansion during backwashing. The column was provided with rotary surface wash mechanism mounted about 7.62 cm (3 in) above the unexpanded carbon bed to aid in the routine column backwashing.

Carbon Regeneration System

The carbon regeneration facility at the pilot plant site consisted of a 7.6 cm (30 in) internal diameter vertical refractory-lined Bartlett-Snow-Pacific, Inc. multiple hearth furnace. As illustrated in Figure 4, the furnace contained six hearths with two gas burners and steam inlets in each of the lower three hearths. The furnace was natural gas-fired with steam added to enhance the regeneration.

The partially dewatered spent carbon from the drain bin was fed by a screw conveyor provided with a variable speed drive so that the desired

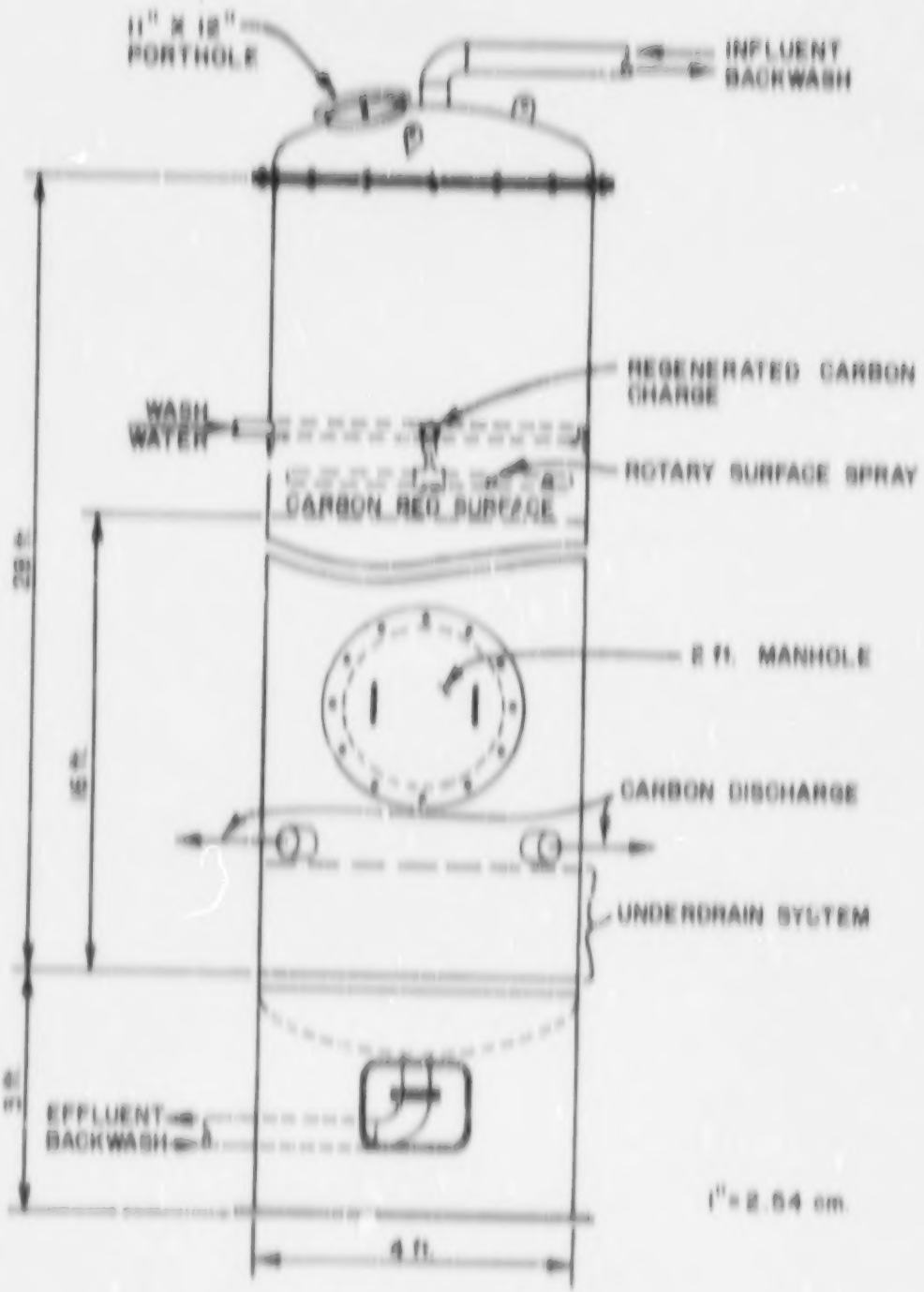


Figure 2. Carbon contactor detail.

TABLE 1. VIRGIN CARBON CHARACTERISTICS

Carbon Characteristics		Calgon Filtrasorb 300 (8 x 30 mesh)
Iodine Number	, mg/g	1040
Apparent Density	, g/cm^3	0.484
Molasses Number		222
Methylene Blue Number,	mg/g	256
Ash ,	%	6.6
Mean Particle Diameter,	mm	1.44
Sieve Analysis ; % retained on #	8	3.5
	10	12.6
	12	19.2
	14	16.3
	16	15.1
	18	9.0
	20	6.8
	30	11.7
	pan	5.8

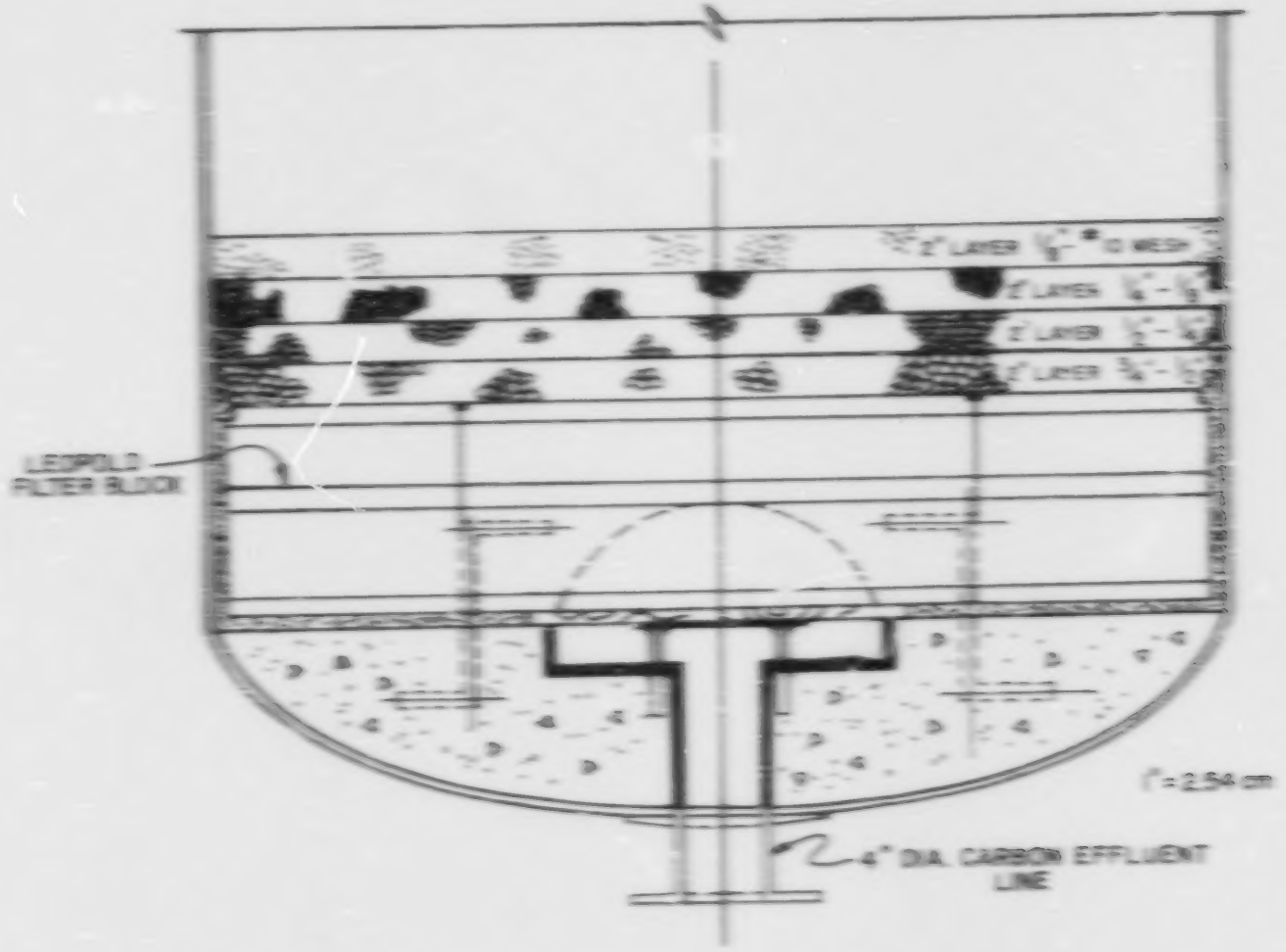


Figure 3. Detail of the carbon column underdrain system.

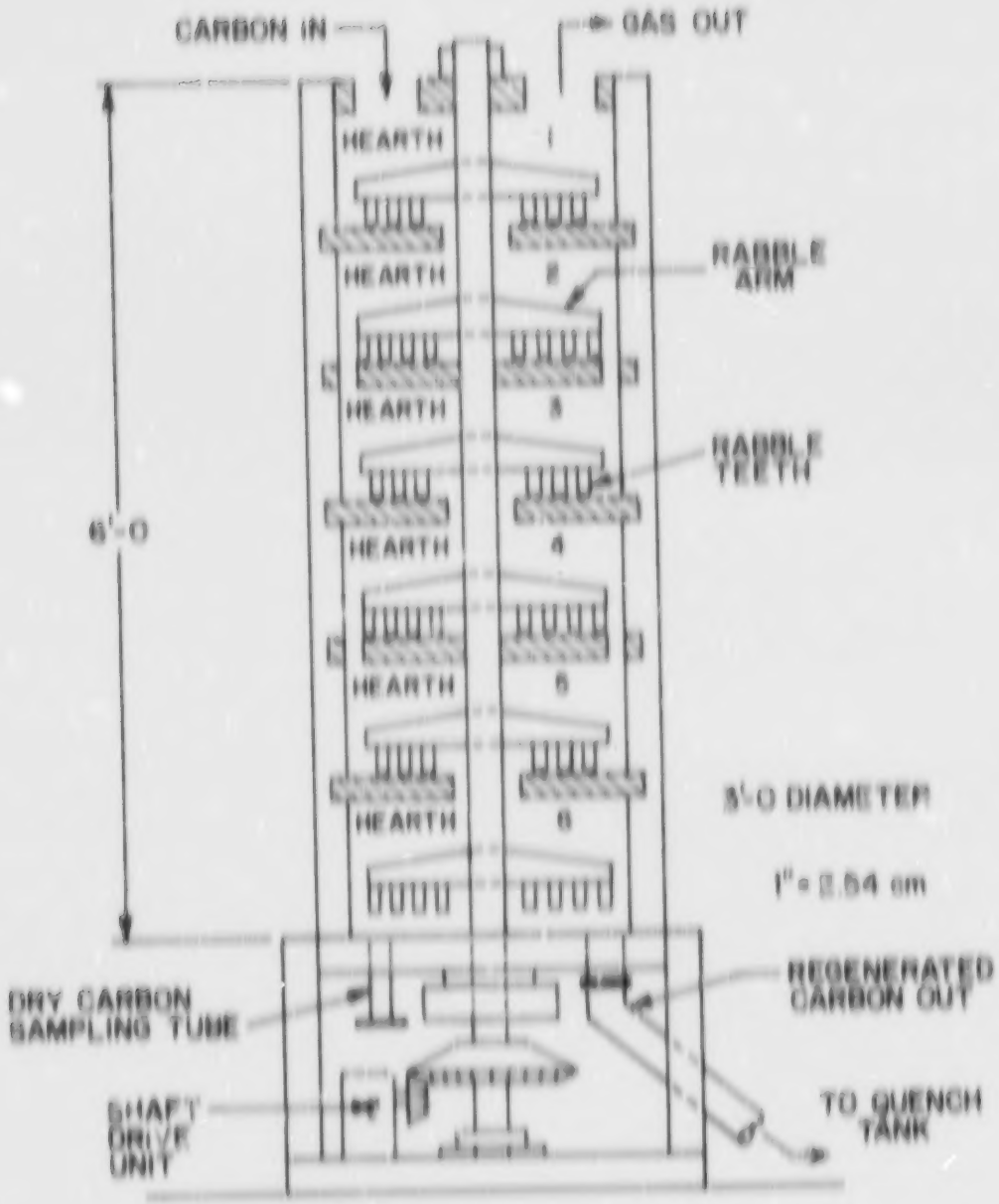


Figure 4. Cross sectional view of the multiple hearth furnace.

rate of carbon fed to the furnace could be accurately controlled. The regenerated carbon was discharged from the furnace through a 7.62 cm (3 in.) diameter stainless steel chute leading from the bottom hearth into a quench tank, from which the regenerated, quenched carbon was continuously educted back to the carbon contactor.

Air Pollution Control System

In order to control noxious odors and particulate emissions, which are the two major air pollutants associated with thermal regeneration of granular activated carbon, the regeneration furnace was equipped with an air pollution control system shown schematically in Figure 5. The air pollution control system consisted of a single cyclone dust separator, a baghouse, and a natural gas-fired afterburner. During carbon regeneration, the furnace flue gases first passed through the cyclone, which was designed to trap all burning particulates 10μ in diameter or larger before reaching the fabric filters in the baghouse. From the cyclone, the gases flowed through a series of ducts into a baghouse. The ductwork leading to the baghouse was provided with a valved connection for dilution air addition. The baghouse was a reversed-air jet cleaned unit (Model 9-6-100 Mikro-Pulsaire Dust Collector manufactured by Mikropul Division of Slick Corporation) containing nine 11.43 cm (4.5 in.) diameter Nomex felt filter bags with a combined filter area of 5.94 sq. m (64 sq.ft.). Each filter bag was 1.83m (6 ft.) long and was designed for a maximum operating temperature of 218.3^{0}C (425^{0}F). The filter bags had a rated porosity of 0.17 to 0.99 cu m/min. (25 to 35 scfm) at 1.27 cm (0.5 in.) water column. The dust-laden flue gases flowing at a rate ranging from 3.96 to 4.53 cu m/min (140 to 160 scfm) entered the lower section of the baghouse and travelled upward through the fabric filter cylinder where the dust particles collected on the exterior surface of the filter bags. A pull-through exhaust fan mounted on top of the baghouse provided the driving force for the gas flow through the system. As the dust mat built up on the fabric surface, the pressure differential across the filters increased to a level at which the deposited solids had to be removed by reverse air flow. In order to control the pressure drop through the filter within the desired limits of 2.54 cm (1 in.) to 15.24 cm (6 in.) of water column, a cyclic timer periodically (2 to 45 seconds interval) actuated solenoid valves which delivered momentary surges of compressed air rated at 7.03 kg/cm^{2} (100 psi). The dust dislodged from the exterior surface of the filters during the reverse jet cleaning operation were collected in a storage drum attached to the discharge hopper of the baghouse. The filtered gases from the baghouse then flowed through the afterburner which was operated between 704.4^{0}C (1300^{0}F) and 760^{0}C (1400^{0}F) for odor control before final discharge into the atmosphere.

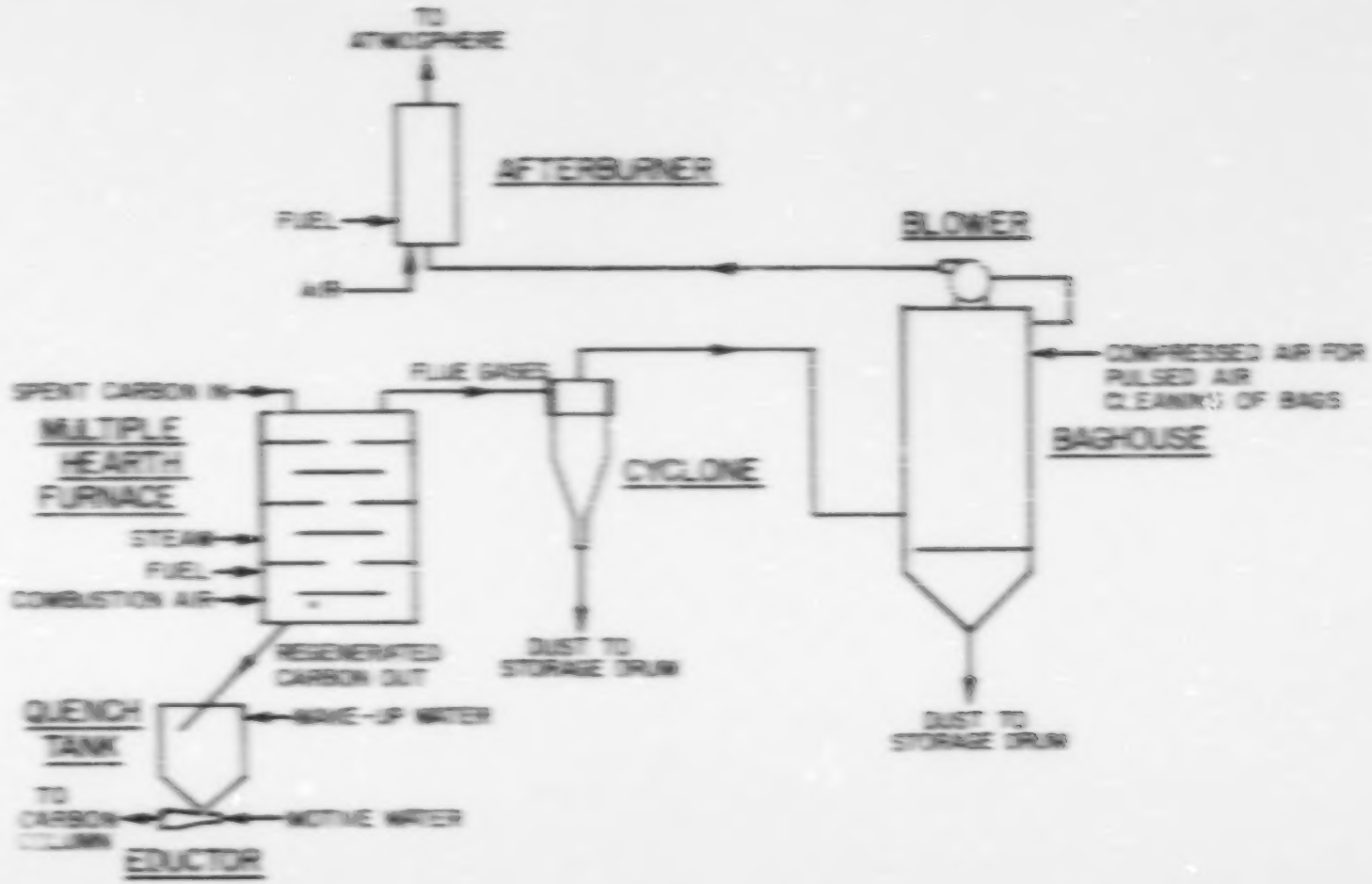


Figure 5. Schematic diagram of the air pollution control system.

Carbon Transfer and Regeneration Procedures

Prior to each regeneration the spent carbon was backwashed with 56.8 m^3 (15,000 gallons) of secondary effluent from the main Pomona plant and hydraulically transferred to the dewatering bin. The dewatered spent carbon, with about 50 percent moisture content, was conveyed through a screw conveyor into a six-hearth furnace where it was regenerated at temperatures ranging from 899°C (1650°F) to 977°C (1790°F). Steam in the amount of 0.5 Kg steam/Kg carbon was added to the lower two hearths to enhance regeneration. The regenerated carbon was discharged from the furnace at the rate of 35-41 Kg/hr (77 to 90 lbs/hr) into a quench tank from which it was continuously educted back into the carbon contactor. The regeneration of one batch of spent carbon normally required 53-66 hours to complete. After regeneration, the regenerated, quenched carbon was backwashed with 75.7 m^3 (20,000 gallons) of secondary effluent to remove the carbon fines and the appropriate amount of virgin make-up carbon was added to replace the carbon lost during the regeneration. The weight of the virgin carbon added to make up to the original volume was used as the measure of the carbon loss. The column, with the added make-up carbon, was then given a final backwash of 7.57 m^3 (2000 gallons) of secondary effluent before it was put back in operation.

SAMPLING AND TESTING PROGRAM

In this study, samples of raw sewage, chemically clarified raw sewage and carbon effluent were obtained 5 days a week using specially designed automatic samplers programmed to collect six 4-hour composite samples a day. Each 4-hour composite was made from samples collected automatically for 3 to 5 seconds once every 15 minutes. For sewage sampling, a Sirco automatic sampler was used in conjunction with the aforementioned sampling devices. The 4-hour composite samples were manually combined to obtain a 24-hour composite sample. All samples taken were refrigerated at 4 °C prior to analysis. The 24-hour composite samples were analyzed daily for total chemical oxygen demand (TCOD), dissolved chemical oxygen demand (DCOD), turbidity, suspended solids and color; two to three times a week for alkalinity, ammonia, nitrite, nitrate, total aluminum and total phosphate; once a week for total dissolved solids, sulfate, organic nitrogen, methylene blue-active substances; and once to twice a month for phenols, minerals and metal constituents. About three times a week, the six 4-hour composite samples were individually analyzed for COD and suspended solids in order to monitor more closely the diurnal variations of these parameters. Tests for pH, temperature, dissolved oxygen (D.O.) and total sulfides were performed three to five times a week on grab samples. Grab samples of chemical sludge were analyzed daily for suspended and volatile solids, and one to two times a week for total phosphate and total aluminum. Periodically during the study, thickening and filtration tests were performed on sludge samples.

Occasionally, 24-hour composite samples from various depths of the carbon column were collected using timer-controlled solenoid valves. These samples were analyzed for DCOD to determine the movement of the soluble organics wavefront through the carbon column.

Analytical Methods

All physical and chemical analyses were performed in accordance with the 13th Edition of Standard Methods (4) or the FWPCA Methods for Chemical Analysis (5) unless otherwise specified.

The mineral and metal analyses were performed using atomic adsorption methods. Dissolved oxygen was determined by the use of Weston and Stack dissolved oxygen analyzer. Turbidity was determined by the use of a Rossum turbidimeter. Tests for ammonia, nitrite, and nitrate were performed using a Technicon Auto-Analyzer. The activated carbon analyses were performed using standardized procedures (6).

The thickening tests were performed using 2-liter graduated cylinders each fitted with a picket rake mechanism operated at a rotational speed of 1 revolution per minute (rpm).

The leaf filtration tests were conducted using a standard 93 cm^2 (0.1 ft^2) Elmco leaf filter under a vacuum of 30 cm (15 in.) of mercury. Two-liter samples of gravity-thickened and chemically-conditioned sludge were used in the filtration tests.

Regeneration Schedule

When the carbon became exhausted based on a predetermined level of either effluent quality or organic loading, the column was taken off stream in preparation for regeneration. In this study, the original criterion for regeneration was a carbon effluent total chemical oxygen demand (TCOD) limit of 40 mg/l. During the virgin adsorption cycle, however, it was found that the carbon effluent TCOD concentration remained practically constant at a level of about 20-24 mg/l through the first 18 months of column operation. Because of this observation, it was decided to disregard the effluent TCOD criterion and to regenerate the carbon. Thus, in the second and third adsorption cycles, the carbon was regenerated every 3 to 5 months without regard to the state of exhaustion of the carbon in an effort to obtain data on the effect of repeated thermal regenerations on the carbon characteristics and performance. The data generated in this study was divided into three groups to correspond to the carbon column operation in between the regenerations.

SECTION 5

EXPERIMENTAL RESULTS

CHEMICAL TREATMENT PHASE

Performance

During the first one and one half months of the study when the carbon column was being installed, ferric chloride, which was available from a previous study was used for coagulation. After this shakedown operating period, ferric chloride was replaced with alum as the primary coagulant. Table 2 presents the performance of the chemical treatment system with ferric chloride addition. The raw sewage TCOD and suspended solids concentration during the ferric chloride addition period was about 50 percent higher than that observed during the major portion of the study when alum was used as the coagulant. Because of the high influent TCOD and suspended solids concentration, the corresponding clarified effluent concentrations were also high. When expressed as percent removal, however, the TCOD and suspended solids removal with ferric chloride were comparable to those observed with alum addition.

Starting in March 1972, when the carbon column was placed in operation until the termination of the study, alum, at an average dosage of 25 mg/l Al (275 mg/l alum) was used as the primary coagulant in the chemical treatment of the raw sewage. During the first month of alum addition, solids-liquid separation in the sedimentation tank was rather poor, resulting in excessive amounts of floc being carried over with the clarified effluent. In order to enhance settling of the alum floc, an anionic polymer (Calgon WT-3000) was added at an average dosage of 0.3 mg/l to the first compartment of the flocculation unit. While alum was fed continuously, the polymer was added for only 12 hours per day corresponding to the period of high alum dose. As mentioned previously, the alum feeding was varied throughout the 24-hour period to approximately match the influent suspended solids concentration. In order to check the effectiveness of the pacing of the alum feed, hourly samples of raw sewage and clarified effluent collected over several 24-hour periods were analyzed for suspended solids. The results of one of these tests are shown in Figure 6. These hourly suspended solids data clearly demonstrate the effectiveness of the chemical clarification system in producing consistent effluent quality. Periodically, during the course of the study, the effectiveness of the dosing pattern was checked by

TABLE 2. SUMMARY OF CHEMICAL CLARIFICATION SYSTEM PERFORMANCE WITH FERRIC CHLORIDE

Ferric Chloride Dosage, mg/l $FeCl_3$	Raw Sewage, mg/l			Clarified Effluent (mg/l)			% Removal		
	TCOD	Susp. Solids	Total P	TCOD	Susp. Solids	Total P	TCOD	Susp. Solids	Total P
60	495	230	11.4	160	52	2.1	67.9	81.4	81.6
107	421	303	12.7	136	52	1.8	71.8	82.8	85.8

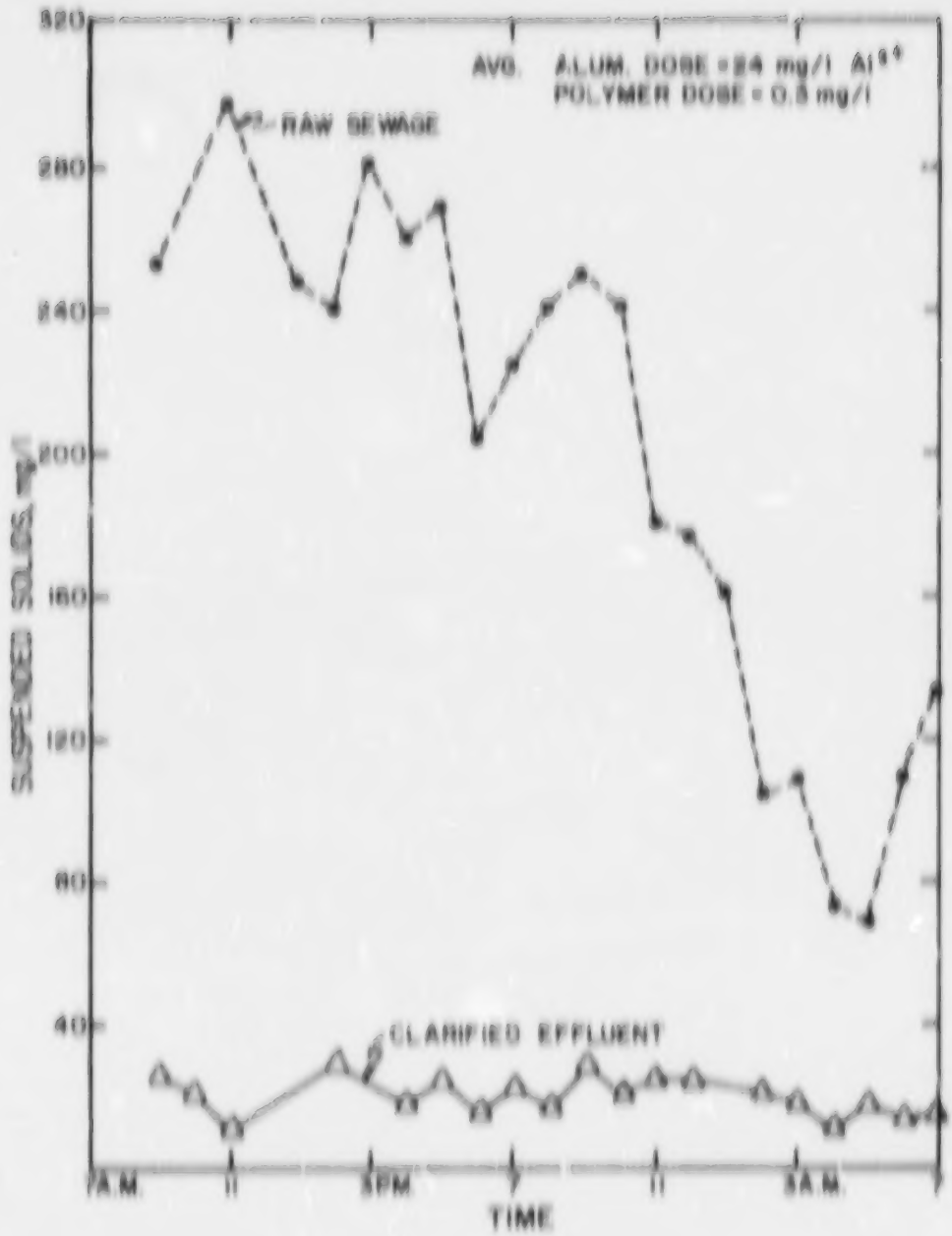


Figure 6. Hourly variation in suspended solids concentration.

routinely analyzing for suspended solids the six 4-hour composite samples of raw sewage and clarified effluent. Typical results of the analysis of the six 4-hour composite samples for suspended solids, which are presented in Figure 7, indicate that the pacing of the chemical dosage was indeed effective in producing chemically clarified effluent of essentially constant quality. Figure 7 was prepared by plotting the average of 17 days data for the month of July, 1972. Data for other months also show similar performances.

Table 3 presents a summary of the average performance of the chemical treatment system during the course of alum addition. The system performance during each of the three periods corresponding to the three adsorption cycles of the granular activated carbon column is shown separately in the table. As indicated in the table, the overall suspended solids and TCOD removal efficiencies in the chemical clarification phase were 85.8 percent and 70.2 percent, respectively. Throughout the study, the chemical treatment system was highly effective and consistent not only in the removal of suspended solids and TCOD, but also in the removal of total phosphate. The chemically clarified effluent had an average TCOD of 95.8 mg/l and an average suspended solids of 28.3 mg/l. The dissolved COD concentration, however, remained virtually unchanged during the chemical treatment. This observation is contrary to what other investigators have found (3,12). The average total phosphate concentration in the raw sewage was reduced from 11.1 to 1.3 mg/l P during the alum treatment. Additional removal of suspended phosphate was achieved through the carbon column thereby boosting the overall total phosphate removal efficiency through the IPC system to 91.9 percent.

Figures 8 through 10 illustrate the weekly average suspended solids removal patterns. The data in these figures along with those presented in Table 3, demonstrate that with the exception of the DCOD removal, the major portion of pollutant removal was accomplished in the chemical treatment system. Moreover, it is apparent from the data that in spite of the considerable variation in the raw sewage strength, the chemical clarification system performance remained relatively stable.

Sludge Thickening and Dewatering Properties

During the first fourteen months of the study, the sludge produced in the chemical clarification system was withdrawn continuously at the rate of 0.17 l/sec (2.8 gpm) without any attempt to thicken the sludge. Because of this continuous sludge withdrawal the sludge produced was rather dilute with an average suspended solids concentration of only 4100 mg/l (ranged from 1700 to 6500 mg/l). From the 15th month until the termination of the study, the sludge pumping operation was placed in an intermittent mode in an attempt to further thicken the sludge in the sedimentation tank. The total daily sludge volume withdrawn amounted to about 1.2% of pilot plant flow. The suspended solids concentration of the sludge varied from about 1 to 2% during the period when intermittent sludge withdrawal was practiced. The sludge contained 1.6 percent total phosphate and 0.3 percent total aluminum on a dry solids weight basis.

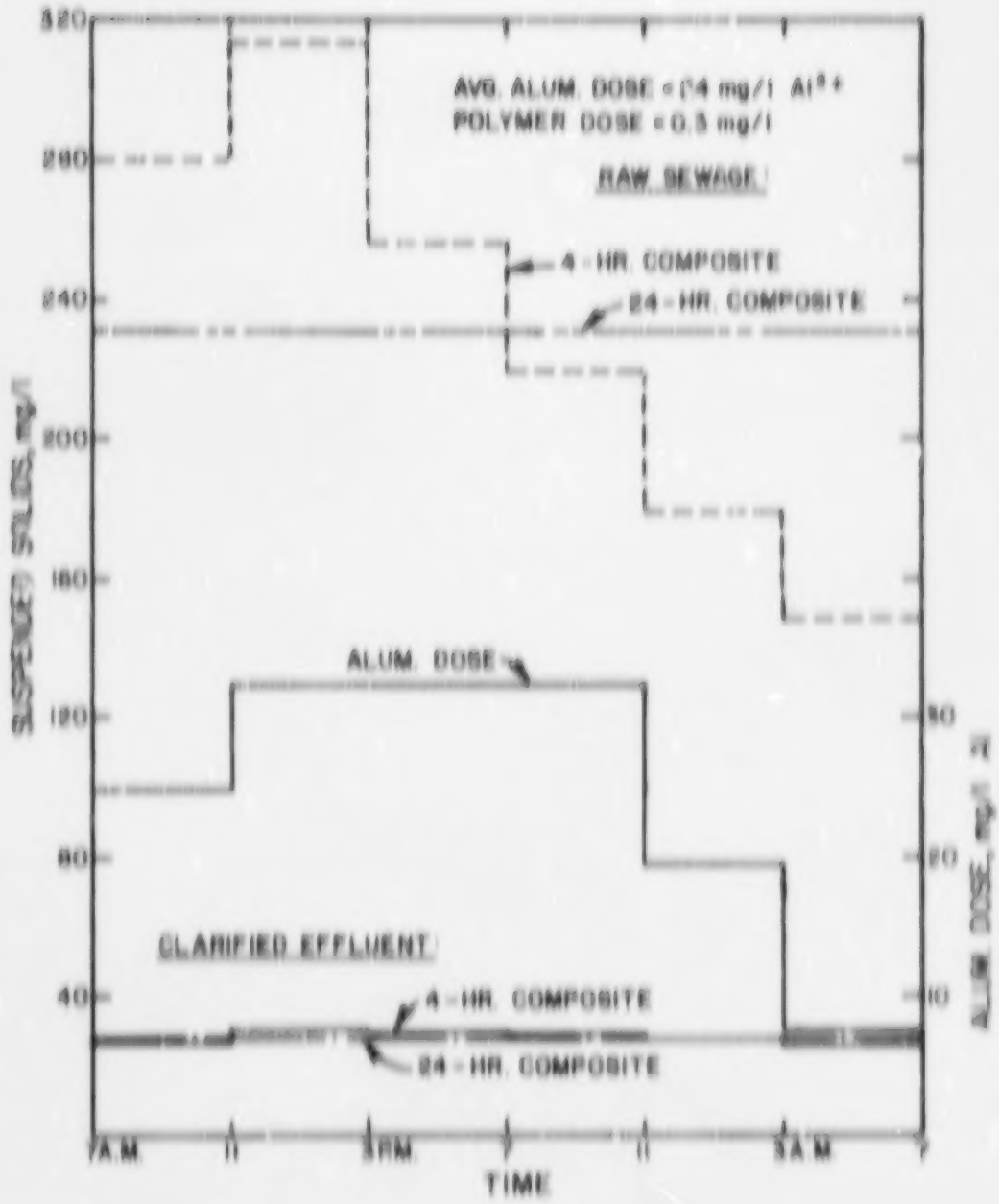


Figure 7. Variation in suspended solids concentration and alum dose.

TABLE 1. SUMMARY OF CHEMICAL TREATMENT SYSTEM PERFORMANCE WITH ALUM AND POLYMER*

Parameters	Raw Sewage				Clarified Effluent				Percent Removal			
	(a)	(b)	(c)	Overall Avg.	(a)	(b)	(c)	Overall Avg.	(a)	(b)	(c)	Overall Avg.
Suspended Solids, mg/l	265	180	198	199	30.9	22.8	24.5	29.3	84.9	87.3	87.6	85.6
Turbidity, JTU					24.4	19.9	20.6	27.9				
TOC, mg/l	105	79.5	105	97.1	58.6	26.7	88.7	35.8	73.3	71.8	68.6	70.7
DOC, mg/l	50.4	45.6	50.8	48.4	48	48.4	52.1	48.6	4.8	---	---	1.6
BOD_5, mg/l					38.9	30.4	33.6	36.2				
Color					19.2	23.4	21.6	20				
Total Phosphate,mg/l P	11.3	11.1	9.6	11.1	1.5	0.86	0.85	1.3	86.7	92.3	91.1	88.3
Nitrate, mg/l N					0.92	.87	.79	.90				
pH	7.65	7.67	7.78	7.68	6.85	6.64	6.40	6.75				

* Average alum dosage = 25 mg/l Al (225 mg/l alum); Average polymer dosage = 0.3 mg/l Calgon WT-3000
(a) 1st cycle average concentration
(b) 2nd cycle average concentration
(c) 3rd cycle average concentration

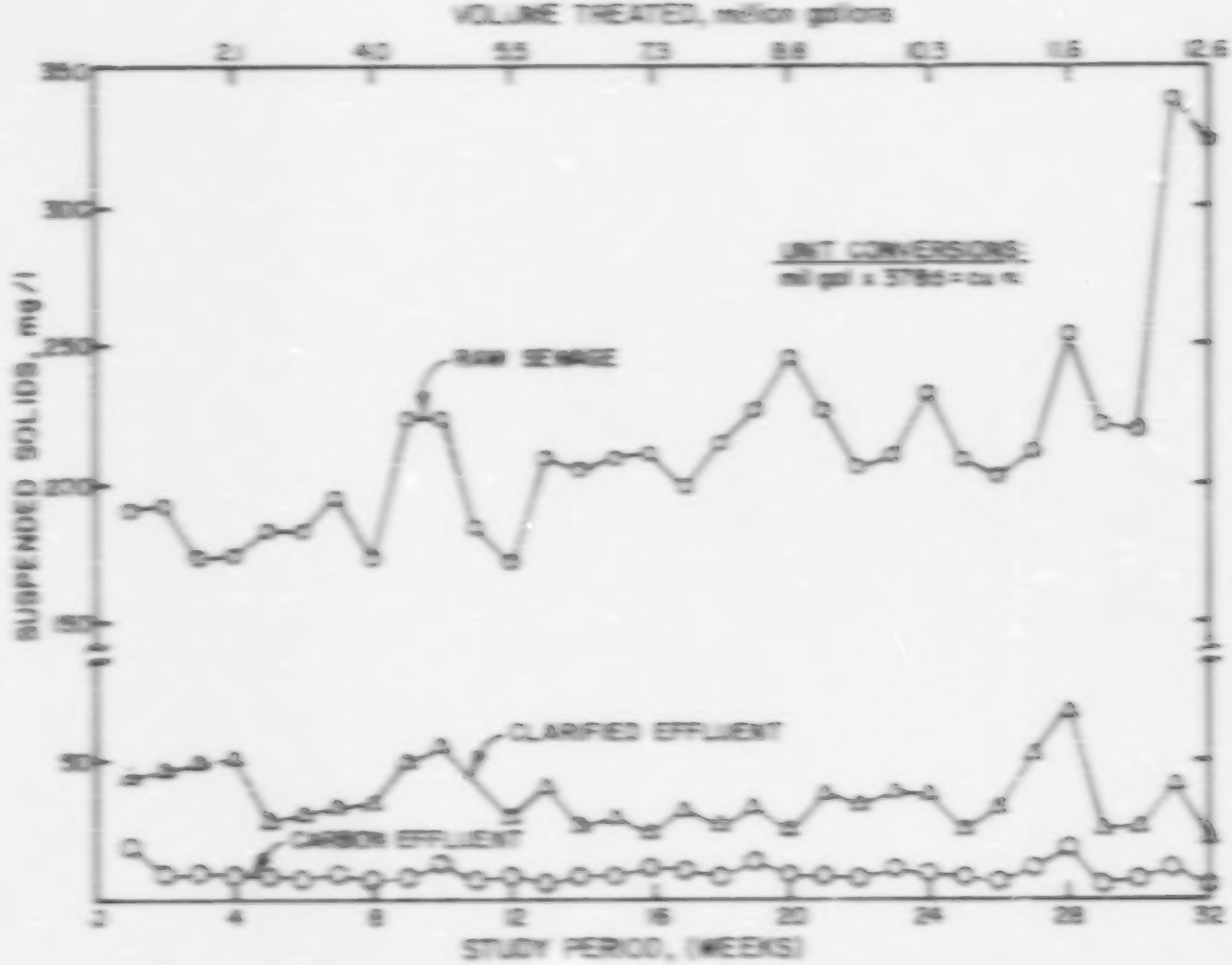


Figure 8 Suspended solids removal pattern in the IPC system - first cycle.

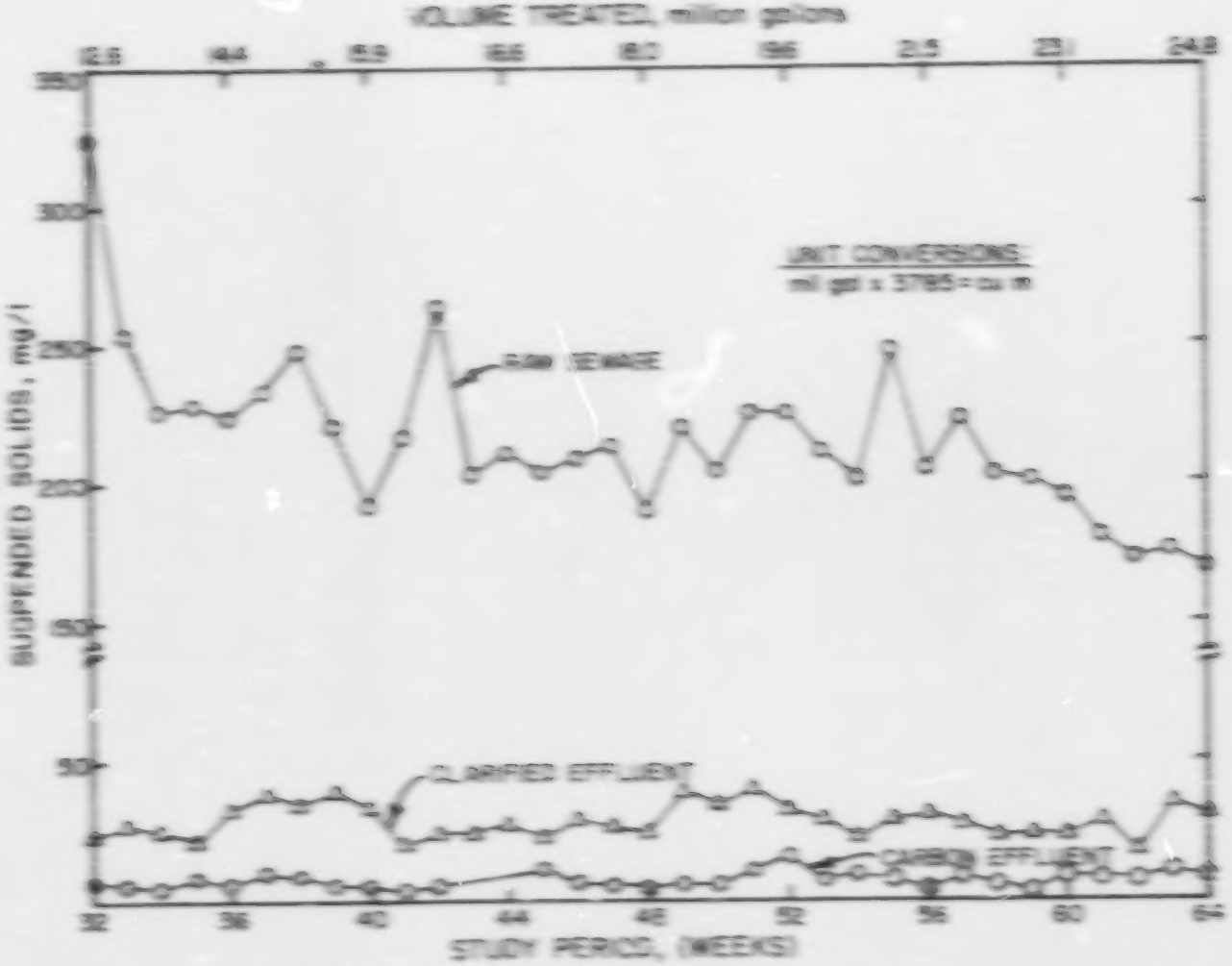


Figure 8. Continued

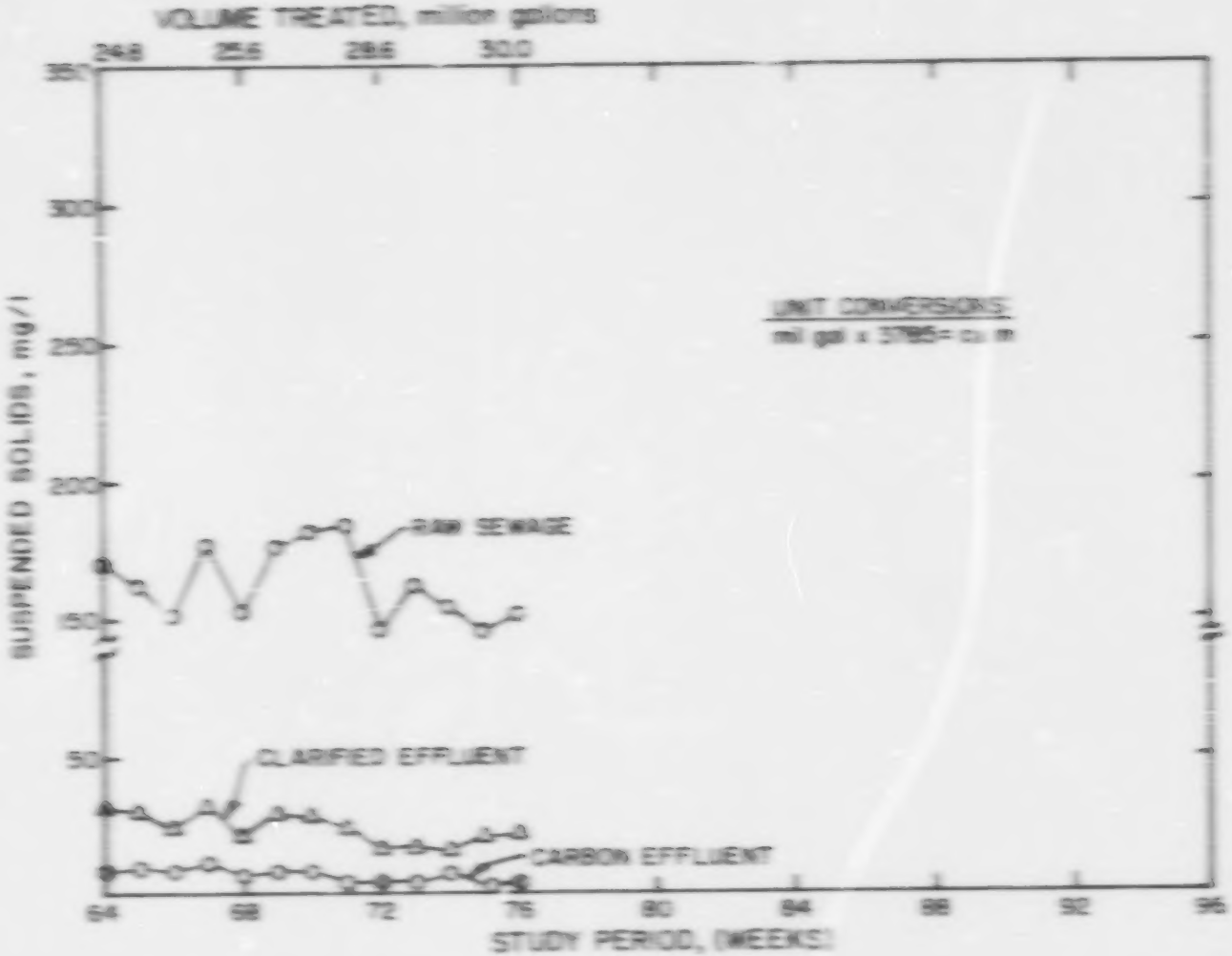


Figure 8. Continued

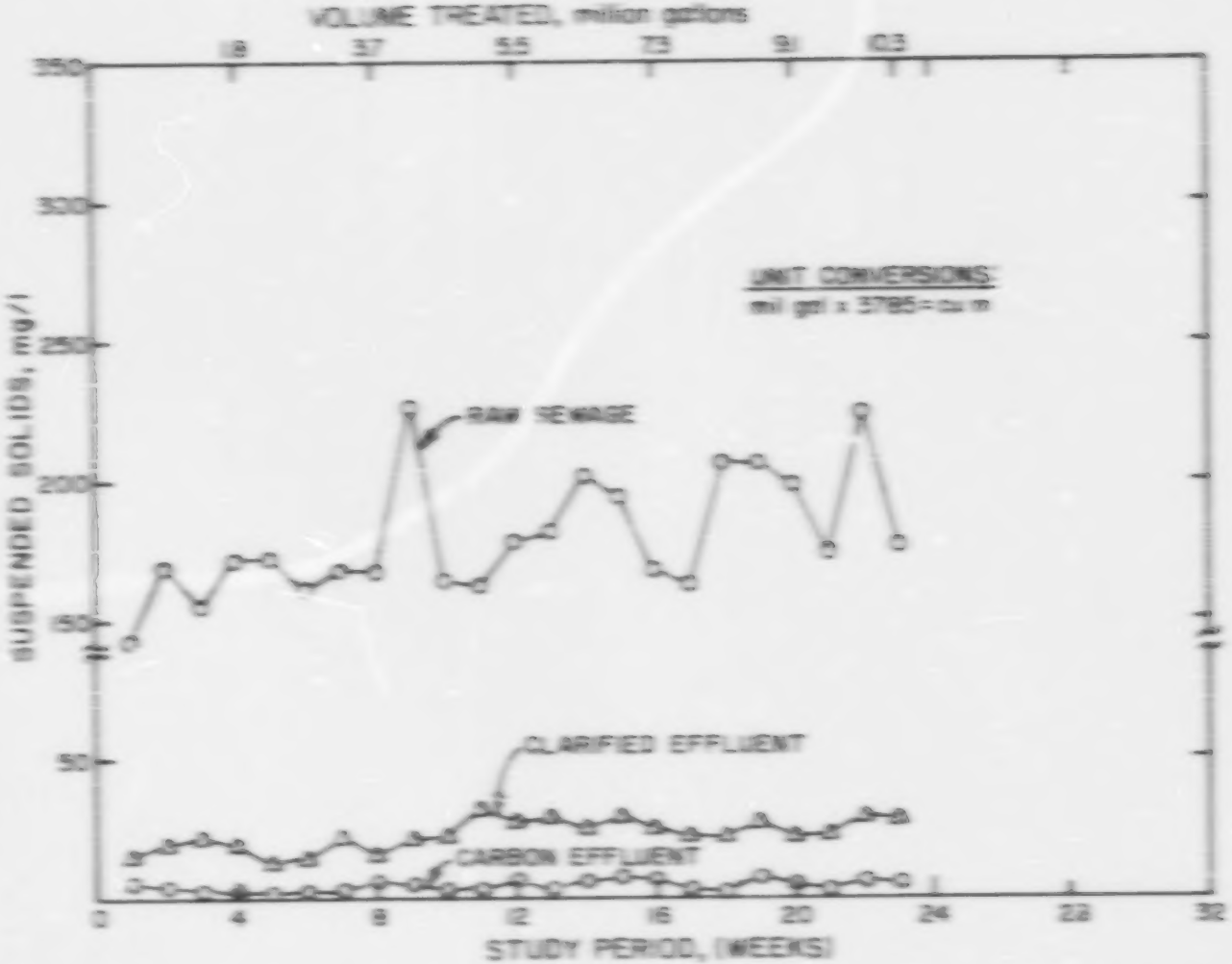


Figure 9. Suspended solids removal patterns in the IPC system - second cycle.

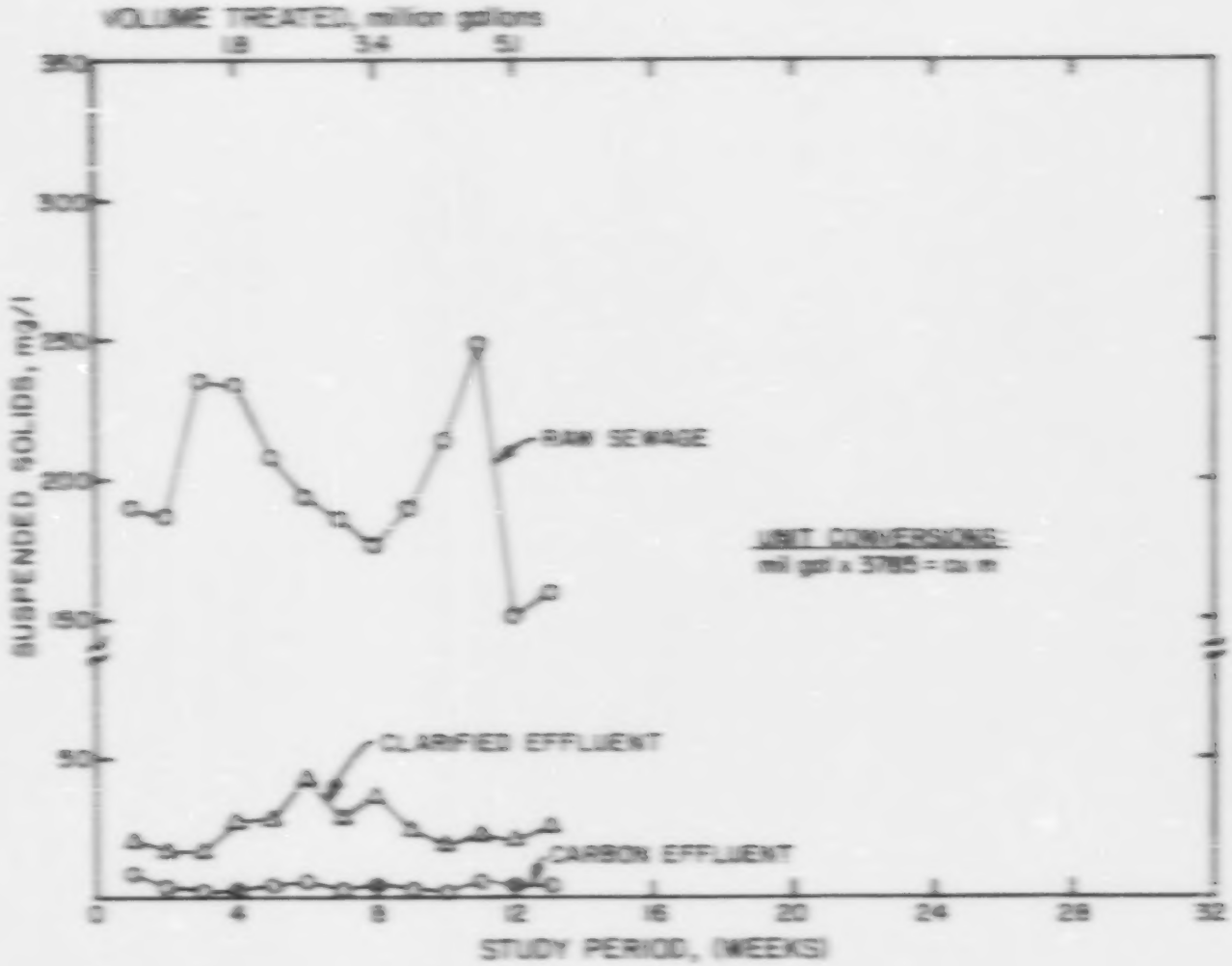


Figure10. Suspended solids removal patterns in the IPC system - third cycle.

In the course of the study, a limited number of batch settling tests were performed on grab sludge samples using two-liter graduated cylinders, each fitted with a picket rake mechanism. The picket rakes were operated at a constant rotational speed of one revolution per minute to reduce wall effects on sludge compaction in the graduated cylinders and thus approximate to a certain degree the settling phenomenon observed in a full-scale thickener. The batch settling tests were performed using various levels of initial suspended solids concentrations with and without the use of polymers as thickening agents. From the sludge settling curves obtained, zone settling velocities were calculated by taking the slope of the initial straight line portion of the settling profile. Figure 11 shows a logarithmic plot of the zone settling velocity as a function of the initial suspended solids concentration. The beneficial effect of polymer on the settling properties of the IPC sludge is shown by comparison of the curves in Figure 11. Figures 12 and 13 present solid flux curves, which were derived by calculation using the zone settling velocity-suspended solids concentration data in Figure 11. These batch flux curves are useful in evaluating a number of alternate thicker design by selecting various possible underflow concentrations. Operating lines drawn tangent to the batch flux plot provide the maximum solids flux through the thickener at the desired underflow concentration. For instance, as indicated in Figure 12, for an underflow concentration of 4 percent solids the maximum solids flux was 61 Kg/m^2/day (12.5 lbs/ft^2/day) for a sludge without polymer and 156.2 Kg/m^2/day (32 lbs/ft^2/day) for sludge thickened with 4.22 Kg/t (9.3 lbs/ton dry solids) of Dow Chemical C-41 polymer. As indicated in Figure 13, the corresponding solids flux for sludge thickened with 0.82 Kg/t (1.82 lbs/ton dry solids) of American Cyanamid polymer 905 N was 597.8 Kg/m^2/day (122 lbs /ft^2/day). While the solids flux data obtained have indicated a significant reduction in the thickener size with the use of polymer as a thickening agent, an economic analysis should be performed in order to determine whether the polymer use is justified.

Several leaf filtration tests were performed using various types of polymers for chemical conditioning. The conditioning agents were evaluated at various cycle times to derive optimum filter performance based on filter yield, cake solids and filtrate quality. The sludge samples were first concentrated to about 2 percent suspended solids concentration by gravity-thickening for a period ranging from 16 to 18 hours. The filter tests were performed using a standard 93 cm^2 (0.1 ft^2) Eimco leaf filter under a vacuum of 38 cm (15 in.) of mercury. For each test run, a 2-liter sample of the chemically-conditioned sludge was used. A monofilament nylon 415 was used as the filter medium in all the leaf filter tests.

The two most important variables controlling directly the economics of sludge dewatering by vacuum filtration are the chemical dosage and the filter yield. Moreover, the ultimate sludge disposal cost is influenced directly by the moisture content of the filter cake produced during the sludge dewatering operation. In an attempt to evaluate the relationships of the

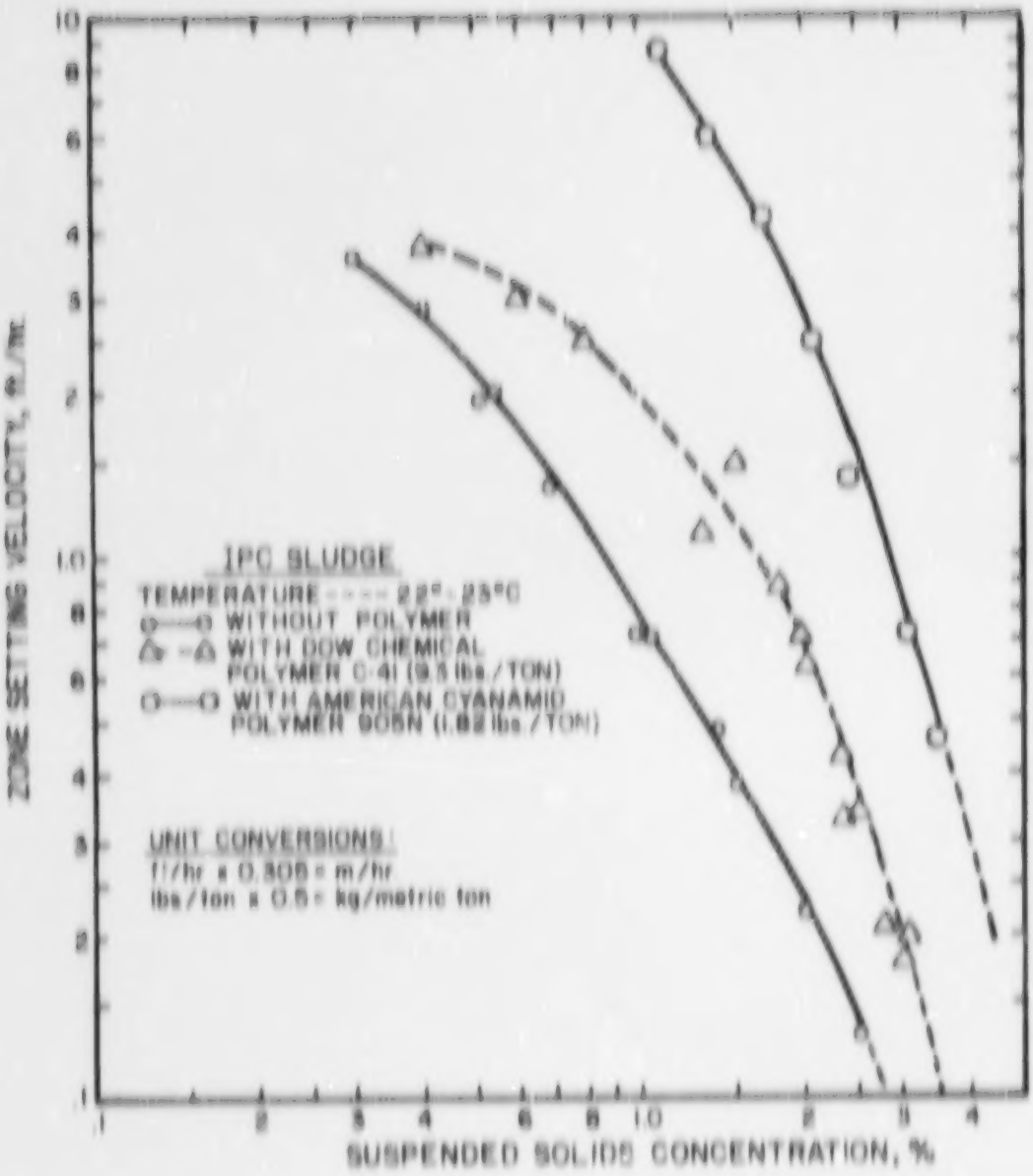

ZONE SETTLING VELOCITY, ft/hr
SUSPENDED SOLIDS CONCENTRATION, %
IPC SLUDGE
TEMPERATURE ---- 22°-25°C
WITHOUT POLYMER
WITH DOW CHEMICAL POLYMER C-41 (9.5 lbs/TON)
WITH AMERICAN CYANAMID POLYMER 905N (1.82 lbs/TON)
UNIT CONVERSIONS:
ft/hr x 0.305 = m/hr
lbs/ton x 0.5 = kg/metric ton

Figure II. Zone settling velocity as a function of suspended solids concentration.

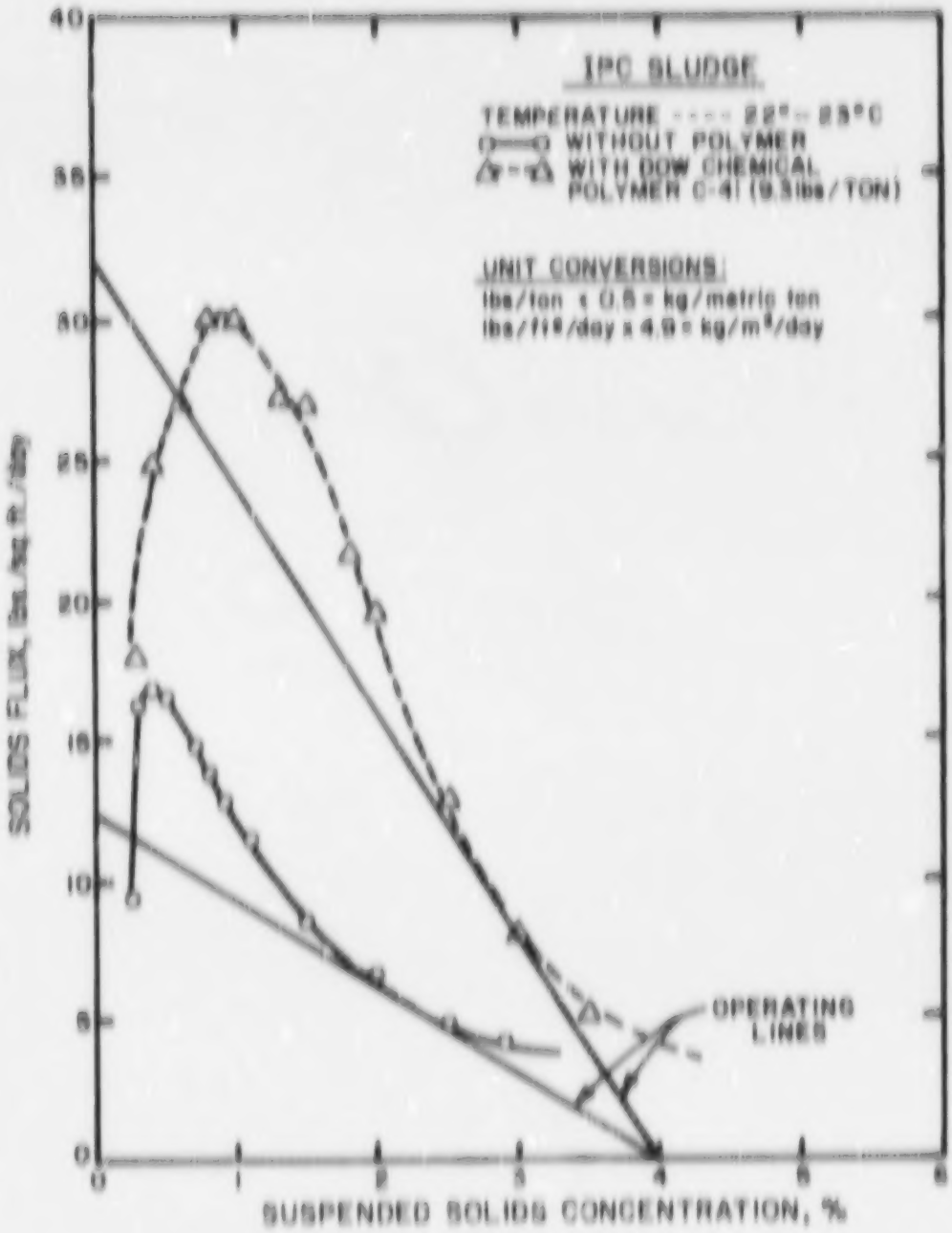


Figure 12. Batch flux curves of IPC sludge with and without polymer.

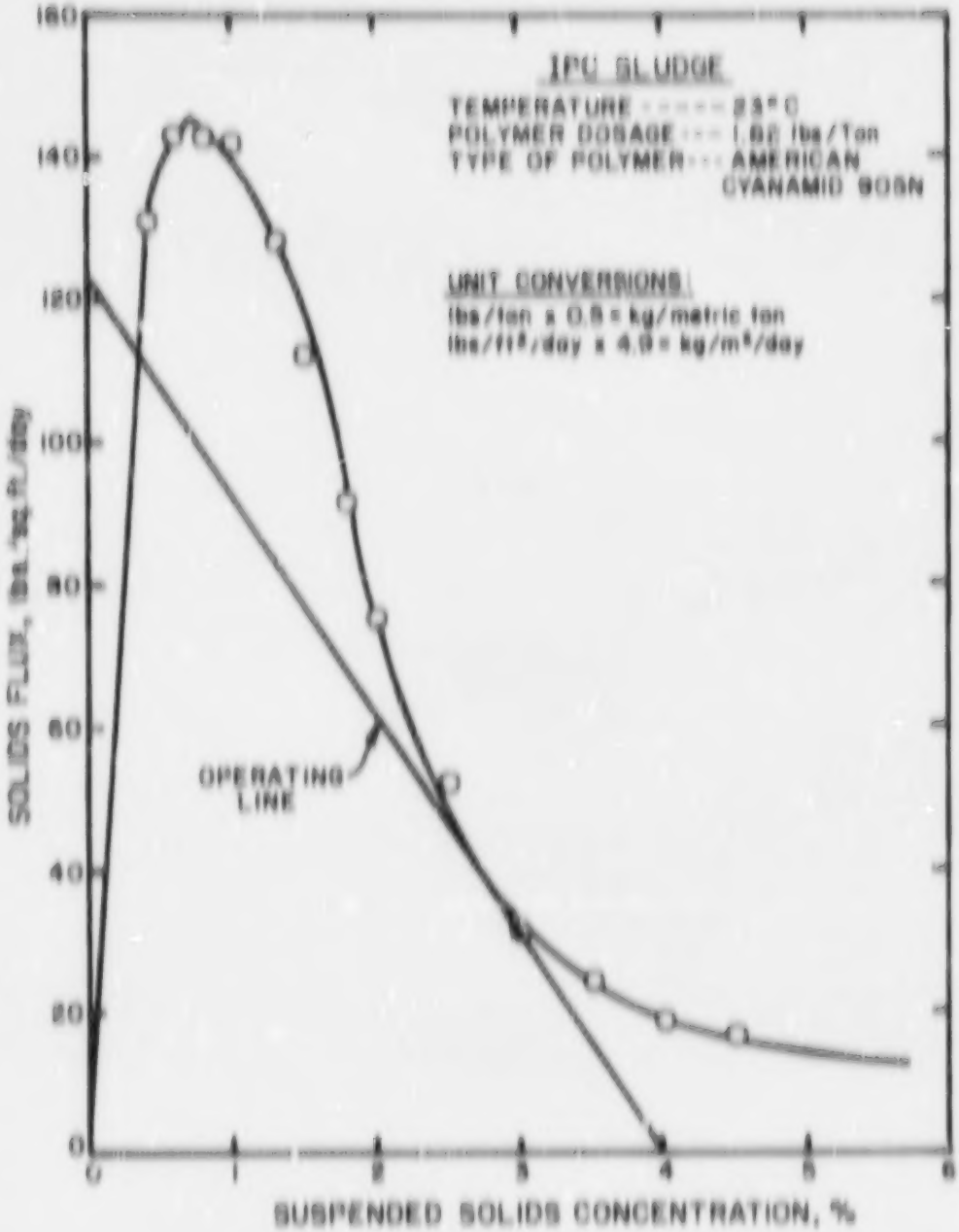


Figure 15. Batch flux curve of IPC sludge with polymer.

aforementioned variables, leaf filter tests were performed using various types of polymers at different dosage levels and under three different cycle times. The test results showed that the filter yield increased with increasing chemical dosage and that the greatest yield increase occurred at the 2-minute cycle time. Moreover, in comparing the data for different cycle times, it is shown that while the lower cycle time provided relatively higher filter yield, it also provided a wetter cake. Thus, in plant scale dewatering operation, a judicious choice of cycle time and chemical dosage should be made in such a way as to achieve an optimum combination of filter yield and cake moisture. Figure 14 summarizes the effect of cycle time on both filter yield and cake solids.

The results of a second series of leaf filtration tests, in which ferric chloride along with six different types of polymers were evaluated at various dosage levels and cycle times, are summarized in figures 15, 16 and 17. The parameters used to evaluate the performance of the various chemical conditioning agents were filter yield, percent cake solids and filtrate suspended solids concentration. To facilitate the comparison of the performance of the various conditioning chemicals, the results are presented in terms of the chemical cost expressed in $/ton dry solids.

Figure 15 shows the effect of chemical dosage at 2-minute cycle time on the filter yield and cake solids. The corresponding data for the 4-minute cycle time is presented in Figure 16. As indicated by the trend of the curves in figures 15 and 16, the filter yield increased with increasing chemical dosage up to an optimum dosage level, beyond which, the yield decreased with further increase in the dosage. Moreover, it is evident from the curves that although higher chemical dosage provided higher filter yield, it also resulted in a wetter cake. The effect of chemical dosage on filtrate quality is shown in Figure 17. In comparing the performance of the various chemical conditioning agents, as shown in figures 15 and 16, it is apparent that under the laboratory test condition, the Dow Chemical C-31 showed the best performance based on filter yield and percent cake solids. However, as depicted in Figure 17, the filtrate contained a high concentration of suspended solids. All the other polymers evaluated produced a clear filtrate at the higher dosage levels. Ferric chloride at a dosage level as high as 12.3 percent by weight of sludge solids was not found effective for IPC sludge conditioning.

Table 4 summarizes the leaf filter test results in which ferric chloride and various types of polymers were used as chemical conditioning agents. The data in the table were obtained from the plot presented in Figure 16. The last two columns of table 4 show the filter yield and the corresponding conditioning chemical cost to obtain 18 percent cake solids. The test results indicated that alum-sewage sludge with initial solids concentration of 1.61 to 2.26 percent were dewatered to 18 percent cake solids with yields ranging from 2.4 to 5.4 Kg dry solids/hr/m^2 (0.5 to 1.1 lbs.dry solids/hr/sq ft of filter area). Of the chemicals evaluated, the Dow chemical anionic polymer A-23 appeared to be the most effective in terms of chemical cost, yield, cake solids, and filtrate quality. Moreover, it is of interest to

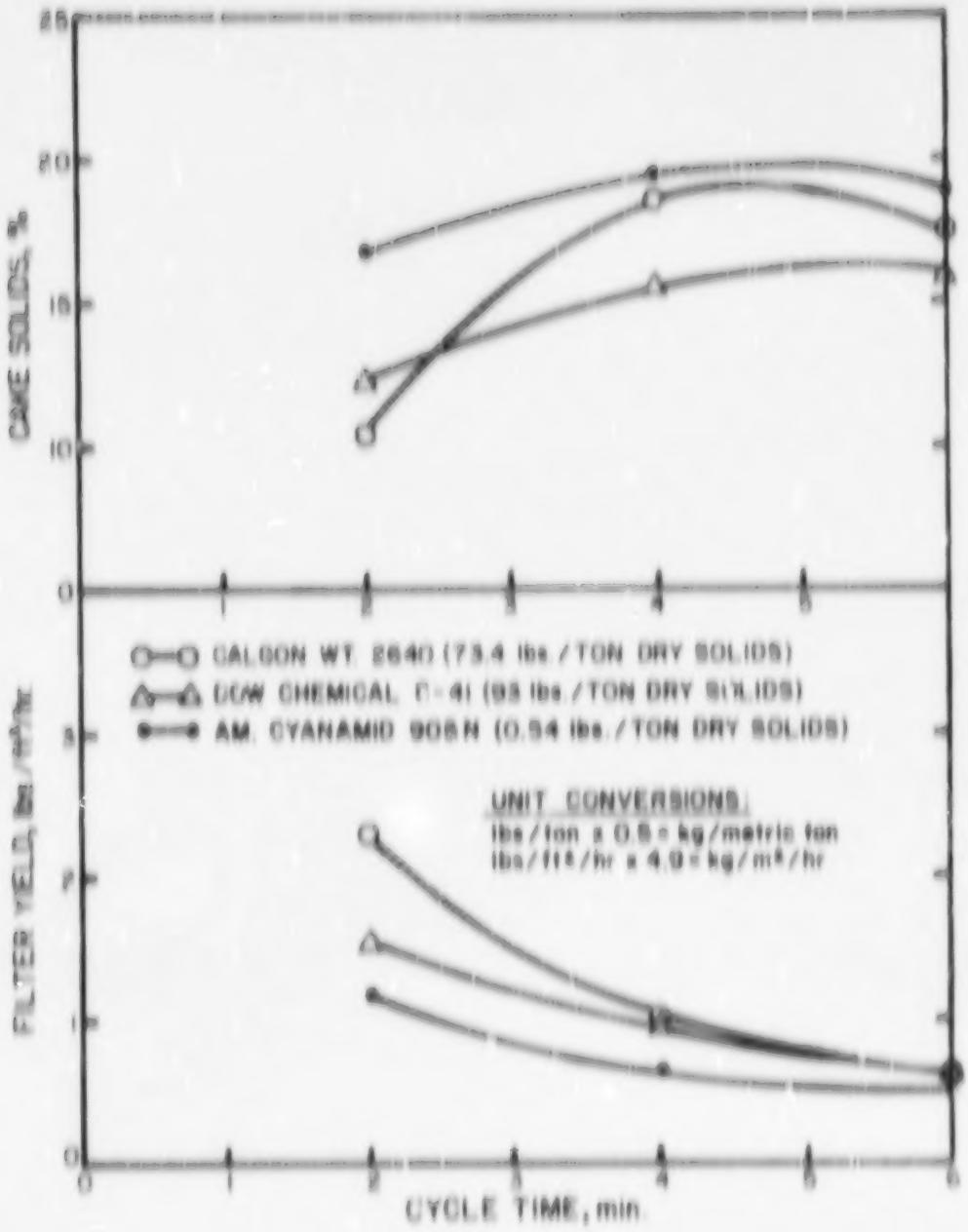

CAKE SOLIDS, %
FILTER YIELD, lbs/ft²/hr
CYCLE TIME, min.
CALGON WT. 2640 (73.4 lbs./TON DRY SOLIDS)
DOW CHEMICAL C-41 (93 lbs./TON DRY SOLIDS)
AM. CYANAMID 909N (0.54 lbs./TON DRY SOLIDS)
UNIT CONVERSIONS:
lbs/ton x 0.5 = kg/metric ton
lbs/ft²/hr x 4.9 = kg/m²/hr

Figure 14. Effect of cycle time on filter yield and cake solids.

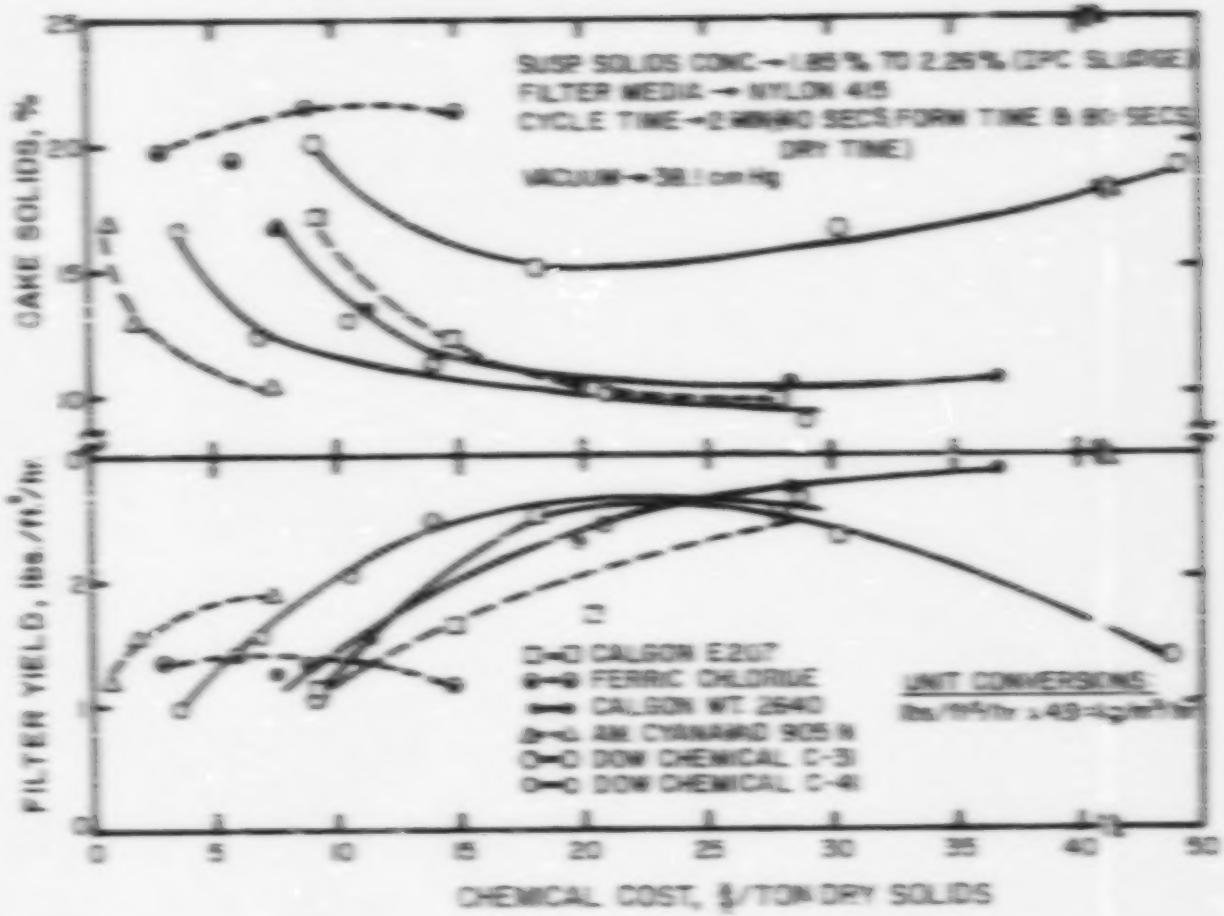


Figure 15. Performance of various chemical conditioning agents at 2 min. cycle time.

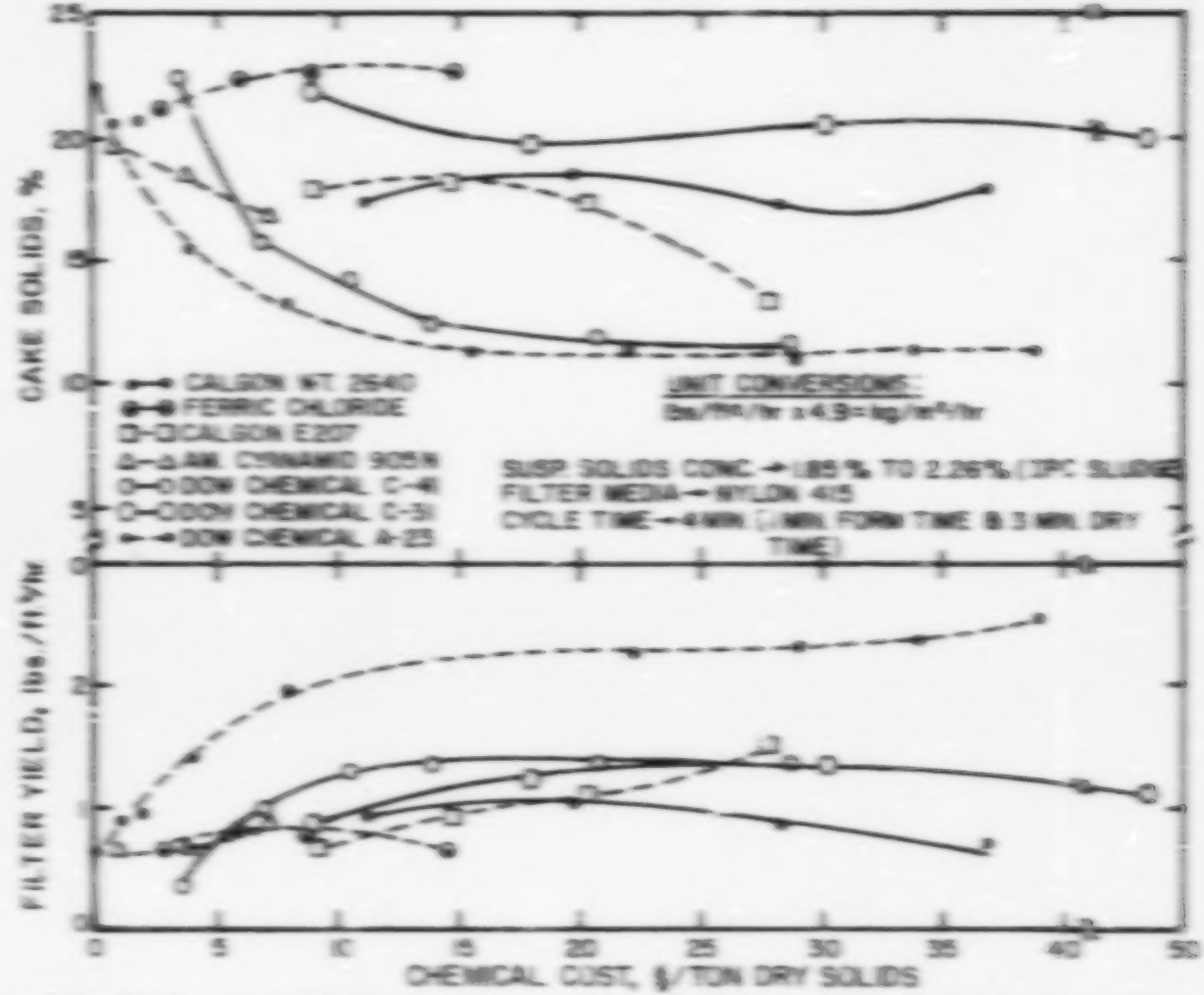

CAKE SOLIDS, %
FILTER YIELD, lbs/ft²/hr
CHEMICAL COST, $/TON DRY SOLIDS
CALGON WT. 2540
FERRIC CHLORIDE
CALGON E207
AM. CYNAMID 9015
DOW CHEMICAL C-41
DOW CHEMICAL C-31
DOW CHEMICAL A-23
UNIT CONVERSIONS:
lbs/ft²/hr x 4.9 = kg/m²/hr
SUSP. SOLIDS CONC. → 1.85 % TO 2.26% (DPC SLUDGE)
FILTER MEDIA → NYLON 415
CYCLE TIME → 4 MIN. (1 MIN. FORM TIME, 0.3 MIN. DRY TIME)

Figure 6. Performance of various chemical conditioning agents at 4 min. cycle time.

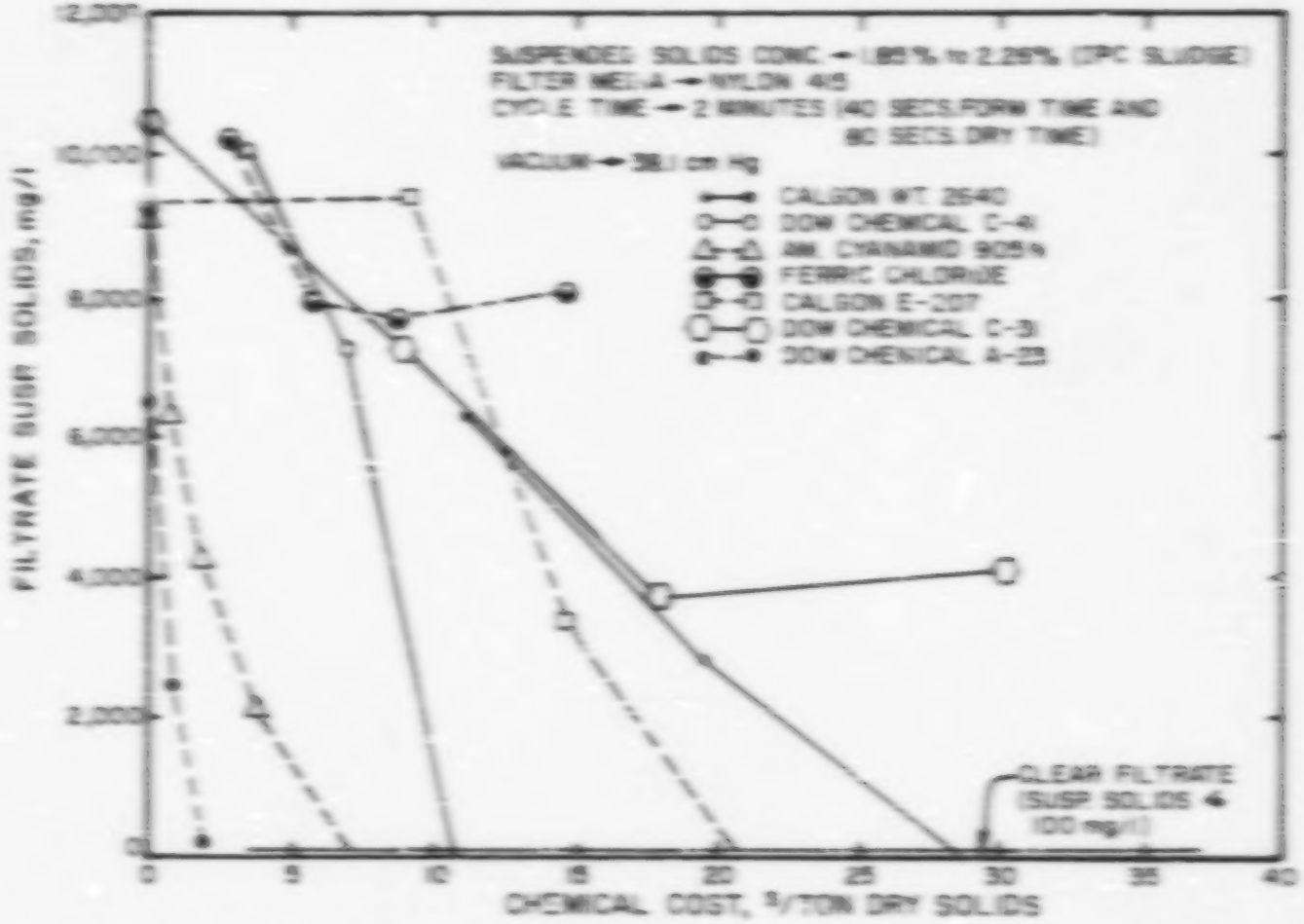


Figure 17. The effect of chemical dosage on filtrate quality.

TABLE 4 LEAF FILTER TEST RESULTS*

Feed Solids, Percent by weight	Conditioning Chemicals Used	Chemical Cost $/kg	Based on Optimum Yield			Based on 18% Cake Solids	
			Yield, kg/hr-m²	Cake Solids %	Cost, $/ton	Yield, kg/hr-m²	Cost, $/ton
1.51	Calgon WT-2540	0.59	4.9	18.5	15	4.9	15
2.26	Calgon E-207	0.86	5.4	17.5	20	4.4	15
2.75	Dow Chemical C-41	0.77	6.4	12.5	14	3.9	5.5
2.05	Dow Chemical C-31	0.68	6.4	20.0	27.5	–	–
1.86	Dow Chemical A-23	3.85	10.8	11.5	15	5.4	7
1.61	Am-Cyanamid 905 %	3.74	5.4	13.0	20	2.4	6
2.04	Ferric Chloride	0.13	1.9	22.5	8	–	–
1.86	None	0	2.3	21.0	0	–	–

* Filter media used was Nylon 415 (Elmco). Cycle time was 4 minutes.

note that at 10 percent cake solids, the filter yield with the use of American Cyanamid 905 N was about the same as that with unconditioned sludge. As previously discussed, although the filter yield increased with increasing chemical dosage, the resulting filter cakes were found to contain higher moisture content except in those runs where ferric chloride, Dow C-31 and Calgon WT-2640 were used.

CARBON TREATMENT PHASE

Sulfide Control Measures

The high concentration of soluble organics applied to the carbon column are known to stimulate prolific biological growths within the column. Although this biological activity enhances the overall carbon capacity for dissolved organics removal (7), severe operational problems frequently occur, such as clogging of the carbon bed and the development of anaerobic conditions with the attendant sulfide generation problem. Pressure buildup and sulfide generation were two major operational problems encountered in the IPC carbon column operation.

In the biological oxidation of organic matter various hydrogen acceptors, either organic or inorganic, are reduced. As indicated in the literature (8,9), microorganisms tend to utilize various hydrogen acceptors preferentially in the order: molecular oxygen, nitrate, sulfate and oxidized organics. In the absence of dissolved oxygen and/or nitrate, sulfate-reducing bacteria depend on sulfate reduction as a mode of anaerobic energy-yielding metabolism with hydrogen sulfide as one of the reduced by-products. For sulfate reduction to take place, the following conditions have to be satisfied: presence of organic matter and sulfates; absence of dissolved oxygen and/or nitrate and an environment with favorable temperature. The biological slimes and deposits provide favorable sites where the microbial environment becomes suitable for hydrogen sulfide generation. Thus, in the use of columnar granular activated carbon beds for filtration-adsorption of chemically clarified raw sewage, the potential for production of hydrogen sulfide is high due to the accumulation of suspended solids and other materials providing a large biomass with a correspondingly high oxygen demand. For this reason, efficient surface washing and backwashing techniques must be employed not only to prevent excessive pressure buildup but also to minimize solids accumulation on the surface of the bed that could trigger sulfide generation.

During the first adsorption cycle, the carbon column was operated continuously for two weeks before hydrogen sulfide was first detected in the column effluent. In an effort to inhibit sulfide production, various control measures were evaluated with varying degrees of effectiveness as indicated by the summary data in Table 5 and in Figure 18. In the first two months of the column operation, the bed was routinely cleaned by surface wash-backwash procedure, as discussed in detail in the following section. During that period, the total sulfide concentration of the column ranged from 1.0 to 5.7 mg/l S, and averaged 2.9 mg/l S. Because of this

TABLE 5. H_2S CONTROL MEASURES IN THE CARBON COLUMN

Control Measures	Remarks
(a) Surface wash - water backwash	Sulfides formed.
(b) (a) + O_2 addition to carbon column to D.O. level 4 mg/l intermittently (4 hrs/day).	A reduction in sulfide formation was observed.
(a) + Continuous O_2 addition to the carbon column to D.O. level of 4 mg/l.	A reduction in sulfide formation was observed. Excessive pressure drop occurred in the carbon column.
(c) Surface wash and air/water backwash techniques.	During the first few days of air/water backwash operation, about 17.8 cm of carbon was lost to the underdrain presumably due to the disturbance of the gravel layer. The bed cleansing efficiency of this technique was not significantly better than that of (a). A slight reduction in sulfide formation was observed.
(d) (c) + aeration of the chemically clarified effluent to D.O. level of 2 - 6 mg/l.	Observed results were essentially the same as (b).
(e) (d) + 20 mg/l Cl_2 added to carbon influent.	Observed sulfide level in the carbon effluent slightly lower.
(f) (d) + 40 mg/l Cl_2 added to carbon influent.	Significant reduction in the sulfide concentration was observed. In addition, column headloss was significantly lower than previously observed.
(g) (d) + $NaNO_3$ addition to carbon influent at 7.9 mg/l.	The continuous addition of sodium nitrate, which is preferentially reduced during the anaerobic process has been the most effective in eliminating sulfides.

TABLE 5 (continued)

Control Measures		Remarks
(h,i)	(d) + $NaNO_3$ addition to carbon influent at 4.5-5.1 mg/l.	Complete elimination of sulfide.
(j)	(a) + $NaNO_3$ addition to carbon influent at 5.4 mg/l.	Complete elimination of sulfide.

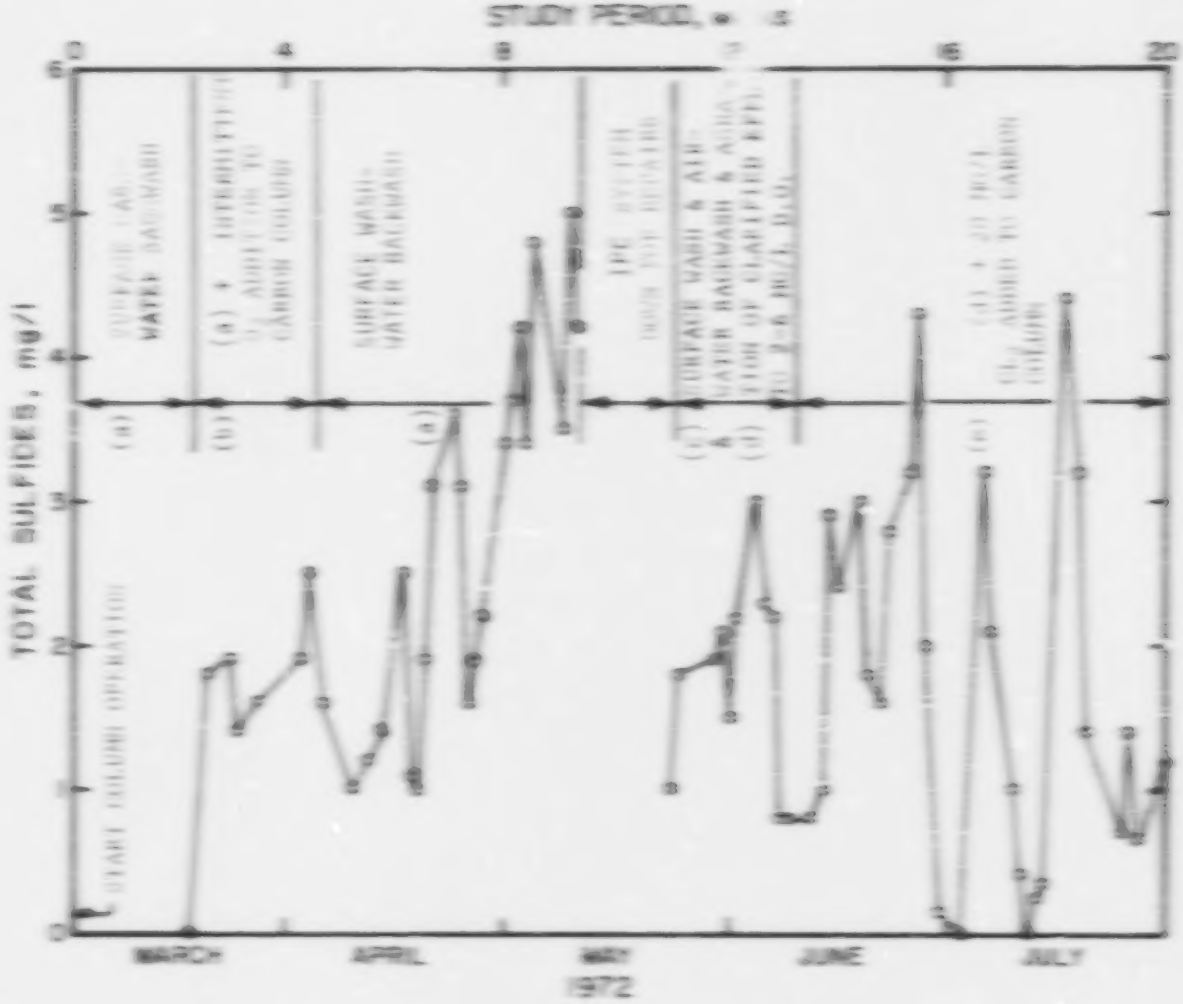


Figure 18. Variation in the carbon effluent total sulfide concentration.

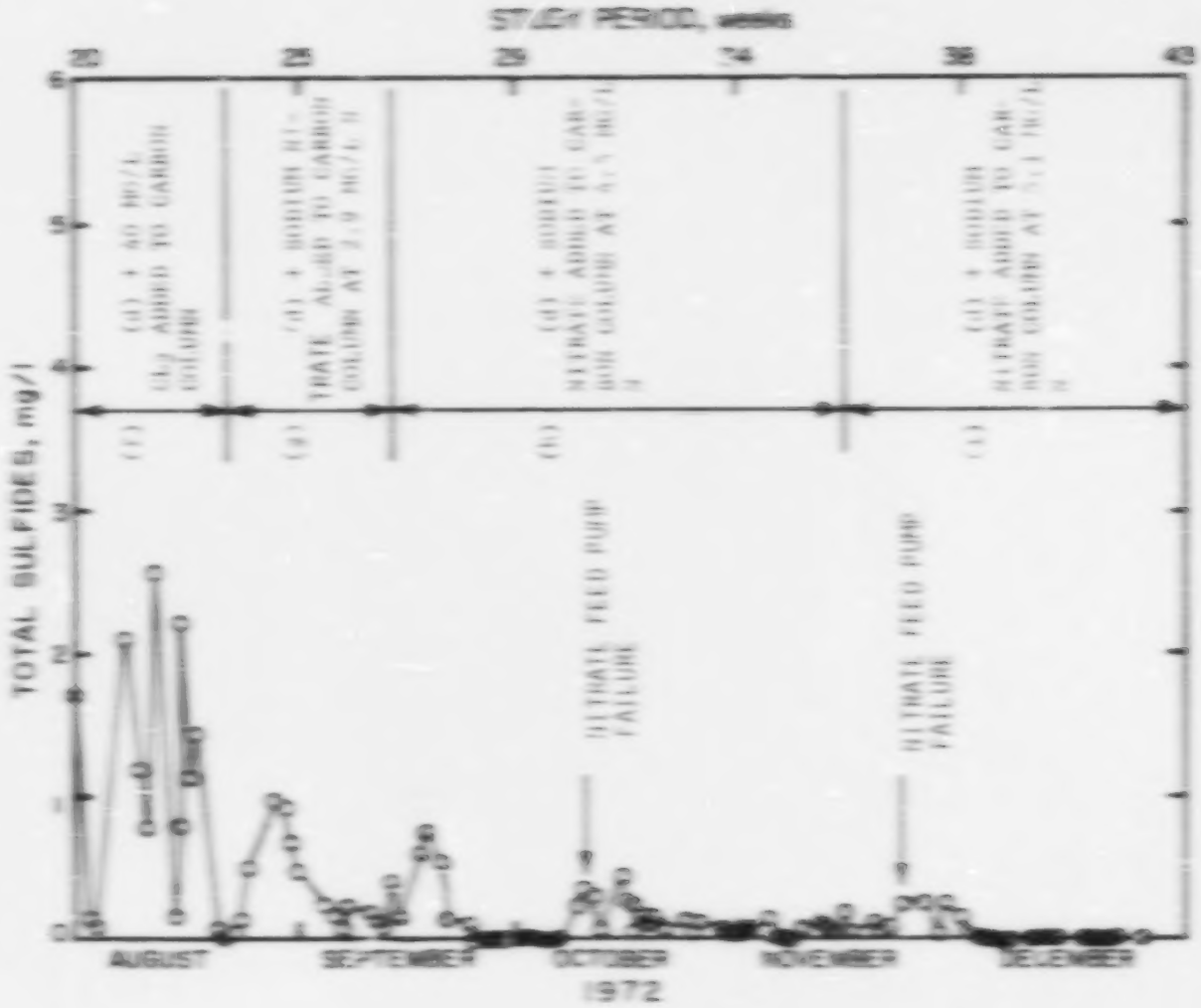


Figure 18. Continued

Figure 6. Continued

high carbon effluent sulfide level, oxygen was added to the carbon column in order to prevent sulfate reduction. Although the carbon effluent sulfide level decreased slightly, this procedure was abandoned because of excessively high headloss which occurred in the carbon column as a result of increased biological activity.

Since sulfate-reducing microorganisms tend to concentrate on biological slimes and deposits, it follows that an effective bed backwashing would help in controlling sulfide formation. Consequently, an auxiliary air scour was used in conjunction with the surface wash-water backwash procedure. The expected benefit of the air-water backwash technique, however, was not achieved. To some extent this may be because the underdrain of this column was not basically designed to function with air scour. Even the oxygenation of the chemically clarified effluent to dissolved oxygen level of 2-6 mg/l in conjunction with the air-water backwash technique did not produce a significant decrease in the carbon effluent sulfide level.

In view of this, another control measure, that of continuous chlorine addition to the carbon influent at dosages ranging from 20 to 50 mg/l Cl, was evaluated. While chlorination of the carbon influent effected some reduction in the total sulfide formed, the results obtained were not at all encouraging because of the high dosage required. Even at a chlorine dosage as high as 50 mg/l Cl, sulfide was still present in the carbon effluent. In addition, although the average total sulfide concentration in the carbon effluent during the high chlorine dosage was only 1.13 mg/l S, at no time during the 21 days of continuous chlorine addition, was the sulfide maintained at a consistently low level. The sulfide concentration in fact fluctuated throughout the period from .09 to 2.6 mg/l S as indicated in Figure 18. It is of interest to note that during periods of chlorine addition, especially at the higher dosage of 40-50 mg/l Cl, headlosses through the carbon column were consistently low in spite of the relatively high influent suspended solids. This observation demonstrates that the high pressure drop observed prior to chlorination and after chlorine addition ceased, were indeed caused by abundant biological growths in the carbon column. Subsequent experience further confirmed the above observation in that drastic increase in headloss occurred when chlorination was interrupted for only a few hours.

In using chlorine for sulfide control in carbon columns, it must be recognized that activated carbon is an effective dechlorination medium. Results of chlorine residual determination of samples obtained at various depths in the carbon column have indicated the complete removal of chlorine at the top 38.1 cm (15 in.) of the carbon bed. The average total chlorine residual in the liquid just above the carbon surface was about 20 mg/l. Since the chlorine was completely removed at the top layers of the carbon column, the viable sulfate-reducing organisms remained virtually unchecked in the lower carbon layers. Unless the sulfate-reducing organisms are completely inhibited throughout the column depth, erratic sulfide inhibition would result as experienced in this study.

Because chlorination at a dosage up to 50 mg/l was neither completely effective in eliminating sulfide formation, sodium nitrate addition to the carbon column was initiated. During the first month of nitrate addition, the nitrate dosage was varied from 1.8 to 3.8 mg/l N. As anticipated, the nitrate was almost completely removed in the carbon column by biological denitrification. The reduction of nitrate in the carbon column was accompanied by high headloss through the bed. The total sulfide concentration of the carbon effluent averaged only 0.36 mg/l S, which was appreciably less than that obtained with chlorination and other methods previously evaluated. From the second to the 7th month of sodium nitrate addition, the nitrate dosage was maintained in the range of 4.5 - 5.4 mg/l N. Thereafter, the nitrate dosage was maintained at an average level of 5.4 mg/l N. The continuous addition of nitrate to the carbon column influent at the dosage of 5.4 mg/l N was found very effective in inhibiting the hydrogen sulfide generation in the carbon column. Figure 18 shows the weekly average total sulfide concentration in the carbon effluent. As shown in the figure, the total sulfide concentration remained consistently at zero level. On a number of occasions, however, nitrate feeding to the carbon column was disrupted due to a malfunction of the chemical feed pump. As a result of the cessation of the sodium nitrate feed, sulfide generation in the carbon column started immediately as indicated in figure 18 by the increase in the carbon effluent sulfide concentration during the middle of October and in the last week of November 1972. Once the sulfate-reducing organisms were established in the column, it took several days of continuous nitrate feeding before sulfide generation was fully controlled. Figure 19 shows detail on the periods when nitrate feed failed. Thus, the data obtained during the periods of unintentional interruption of sodium nitrate feeding proved valuable in demonstrating the need for continuous nitrate feeding to achieve sustained control of hydrogen sulfide generation. A comparative performance of the various hydrogen sulfide control measures is shown in Table 6.

In the second and third adsorption cycles, nitrate addition was not started until after the first two weeks of operation when sulfides appeared in the column effluent. The sulfide level was virtually zero in the column effluent throughout the second and third cycles, except for occasional periods when malfunction of sodium nitrate feed pump occurred.

Column Headloss Data

Since the granular activated carbon column was operated in a packed-bed, down flow mode, the column served as a deep bed filter and as an adsorber. Thus, the direct application to the column of chemically clarified effluent which contained suspended solids ranging from 25-40 mg/l led to progressive clogging of the bed with an attendant increase in headloss. In addition, bacterial growth in the bed played a significant role in the development of bed pressure drop. To maintain proper column operation, the column was backwashed on a daily basis with a volume of secondary effluent

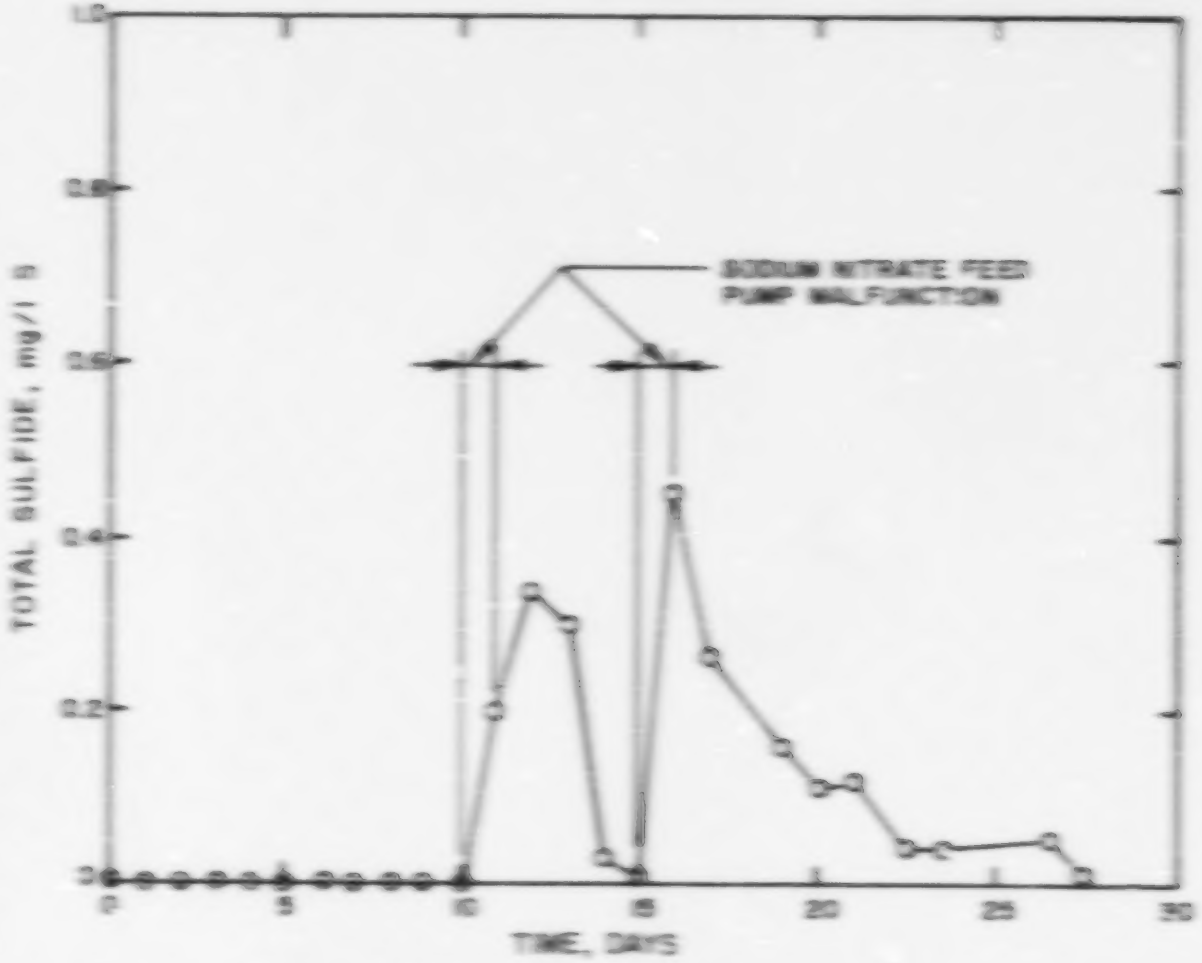


Figure 9. Effect of nitrate feed disruption on sulfide production.

TABLE 6. PERFORMANCE OF THE VARIOUS H_2S CONTROL MEASURES

H_2S Control Measures	Carbon Effluent Total Sulfide Conc., mg/l S	
	Average	Range
(1) Surface wash-backwashing technique	2.86	1.0 - 5.7
(2) (1) + intermittent O_2 addition to carbon column at D.O. level = 4 mg/l	1.85	1.4 - 2.5
(3) Surface wash + air/water backwash plus oxygenation of the chemically clarified effluent to D.O. 2-6 mg/l	1.87	0.8 - 3.0
(4) No.(3)+ 20 mg/l Cl_2* added to carbon influent	1.74	0 - 4.3
(5) No.(3)+ 40 mg/l Cl_2 added to carbon influent	1.13	0.09- 2.6
(6) No.(3)+ 2.9 mg/l N+ added to carbon influent	0.3	0 - 0.95
(7) No.(3)+ 4.5 mg/l N	0.13	0 - 0.60
(8) No.(3)+ 5.1 mg/l N	0.05	0 - 0.26
(9) No.(1)+ 5.3 mg/l N	0.019	0 - 0.10
(10) No.(1)+ 5.4 mg/l N	0	0 - 0.05

* Added as sodium hypochloride solution.
+ Added as sodium nitrate solution.

equivalent to 6 to 8 percent of the product water. During the course of the study a number of carbon bed cleaning procedures were evaluated. The actual backwash duration varied from 30 to 60 minutes depending on the procedure used. Initially, a surface wash-water backwash procedure was used. After the column was on stream for several days, with the routine daily surface wash-water backwash bed cleaning procedure, it was found that at the end of 24 hours of column operation, the water drained very slowly from the carbon column. Thus, during the first adsorption cycle, which covered the first 10 months of the study, the rotary surface spray was used without draining the carbon bed. At the end of the first adsorption cycle an auxiliary drain line was installed in the carbon column which made it possible to drain the water in the column to about 38 cm (15 in.) above the carbon bed before initiating the surface wash cycle. This auxiliary drain line was used starting with the second adsorption cycle until the completion of the study.

Figure 20 shows the surface wash-water backwash schedule. During backwashing the backwash water was discharged into a holding tank designed to capture any accidental carbon spills and to allow visual observation of the clarity of the backwash water. The backwash water containing chemical-biological floc and some carbon fines overflowed a weir in a holding tank and was pumped into the head end of the primary clarifiers of the Pomona activated sludge plant.

For a period of about six months during the first adsorption cycle, an auxiliary air scour was used in conjunction with the regular surface wash-water backwash method in an attempt to achieve better bed cleaning and to provide a means of controlling sulfide generation. Figure 21 shows the air-water backwash schedule. The air was injected directly into the backwash line. The air-water backwash procedure was found to be only slightly more effective than the regular surface wash-water backwash procedure. It should be pointed out, however, that the column, which was provided with the Leopold filter blocks underdrain system, was not designed for air injection and this could have accounted for the performance observed with the air scour method. The loss of about 87 kg (191 lbs) of carbon through the underdrain system during the first few days of the air-water backwash operation demonstrated that the column underdrain system was not suited for air injection. This carbon loss probably occurred when the sudden surge of air disturbed the graded gravel layers.

The effectiveness of the various backwash procedures is shown by the observed column headloss just after backwash and also by the rate of subsequent headloss buildup. The headloss just after cleaning was found to be essentially the same irrespective of the bed cleaning procedure used. The daily headloss buildup, however, fluctuated considerably during the course of the study. A regression analysis of the net headloss (headloss before the daily backwash minus headloss after backwash) and the column influent suspended solids showed no correlation between the two variables. This lack of correlation suggests that the major portion of the headloss

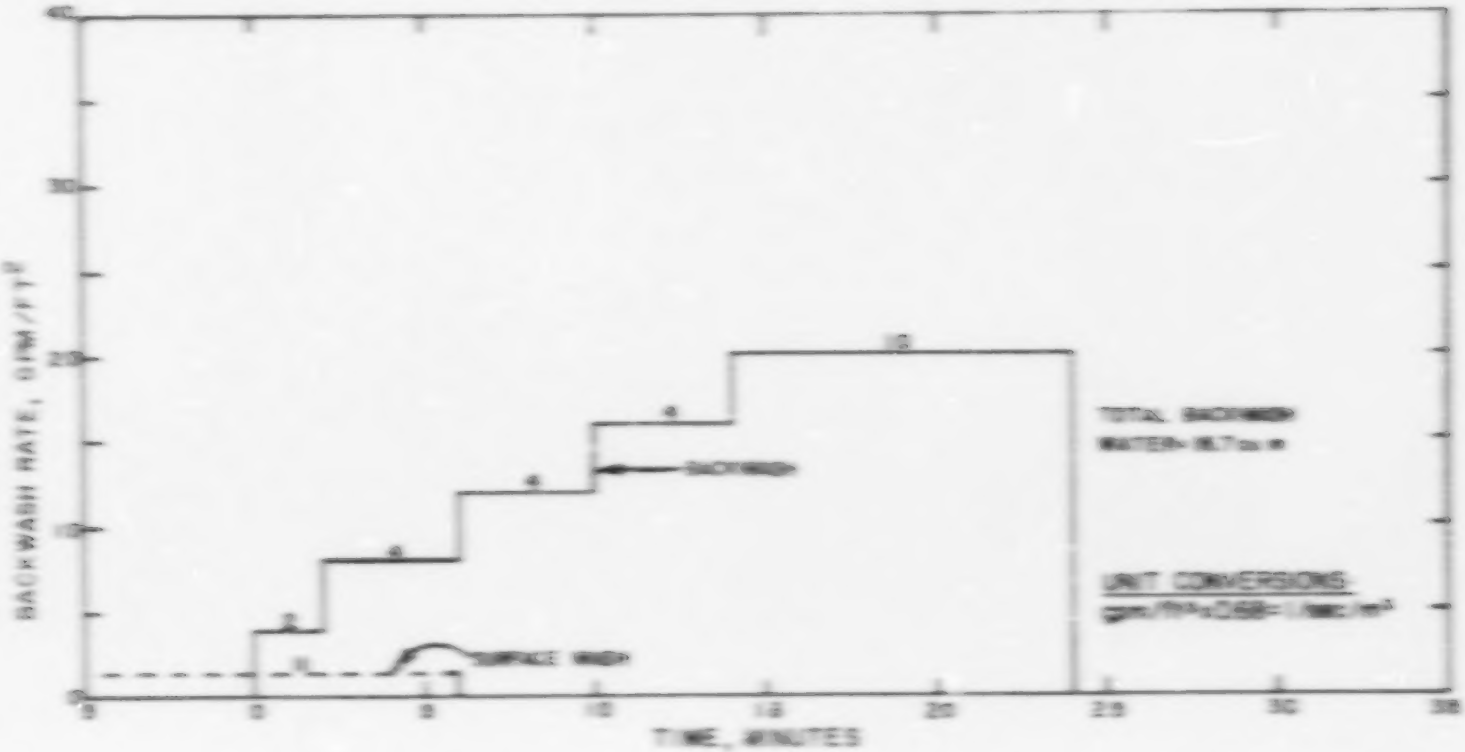


Figure 20. Surface wash- water backwash schedule.

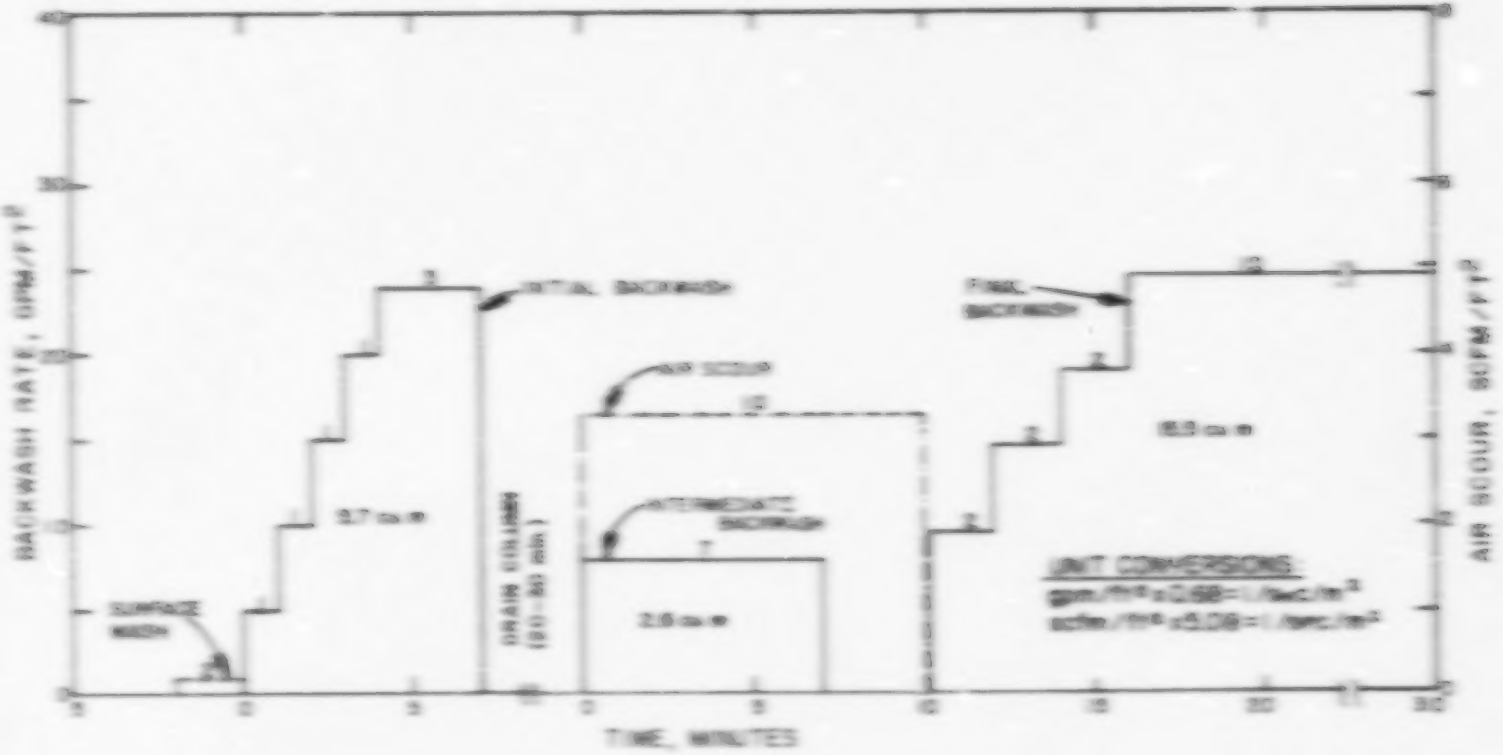


Figure 21. Air-water backwash schedule.

was due to biological growths within the carbon-bed which were not completely removed during the routine backwash. The variations in the weekly average net headloss and influent suspended solids concentration are presented in Figure 22 for the first cycle, Figure 23 for the second cycle and Figure 24 for the third cycle. As indicated in Figure 22, the pressure losses through the carbon column were very low, ranging from 0.11 to 0.25 kg/cm^2 (1.6 to 3.6 psi), during the first four weeks (week No. 1 to 4 of column operation). On two other occasions, weeks 11 and 45, the pressure losses were also low following a period when the column was out of service for extended periods for repairs. Moreover, relatively low headlosses, ranging from 0.56 to 1.38 kg/cm^2 (7.0 to 19.6 psi), were observed during the period (weeks 1) to 23) when chlorine was added to the carbon column influent for sulfide control; however, with the termination of chlorine addition and the subsequent use of sodium nitrate for sulfide control, generally higher headlosses were observed. On several occasions, pressure losses exceeding 3.5 kg/cm^2 (50 psi) before the daily backwash cycle were recorded. As indicated previously, these high pressure losses were probably due to biological solids which accumulated on and near the top layers of the carbon bed. These excessive pressure losses were similar to those observed in previous studies at Pomona(10) when granular activated carbon columns were used for denitrification purposes.

As shown in Figure 24, the headlosses during the first three weeks of the third adsorption cycle were also low and exhibited about the same as that in the first adsorption cycle. In the second cycle, however, the headloss which is shown in Figure 23 were high during the first two weeks following carbon regeneration. These observed high headlosses were probably due to carbon fines which were not completely removed in the initial extended backwash following the carbon regeneration. In subsequent periods, weeks No. 3 to 7, the headloss ranged from 0.2 to 0.62 kg/cm^2 (2.8 to 8.8 psi) and showed about the same headloss pattern as in the first and third adsorption cycles.

In a two-day period in December, 1972, about 27.94 cm (11 in.) of carbon depth equivalent to 136 kg (300 lbs) carbon was lost from the carbon column. This appreciable amount of carbon loss, coupled with the observed high headloss at the top 38.1 cm (15 in.) of the carbon bed prompted an examination of the routine backwash procedure. It was found that the flow through surface spray line, which normally was about 0.02 l/sec (1) gpm) with the valve fully opened, increased to about 3.16 l/sec (50 gpm). This observation led to the examination of the column interior. It was then discovered that the entire rotary surface spray assembly including its supply pipe was dislodged from its support and buried in the carbon bed. Accordingly, the column was taken out of service and the carbon, after a thorough backwash, was hydraulically transferred to an empty carbon column in order to retrieve the surface spray assembly. The rotary spray assembly was found intact whereas the 3.81 cm (1 1/2 in.) diameter supply line (schedule 40,304 stainless steel pipe) was sheared at two locations. The shear failures occurred at the threaded connections where the pipe thickness

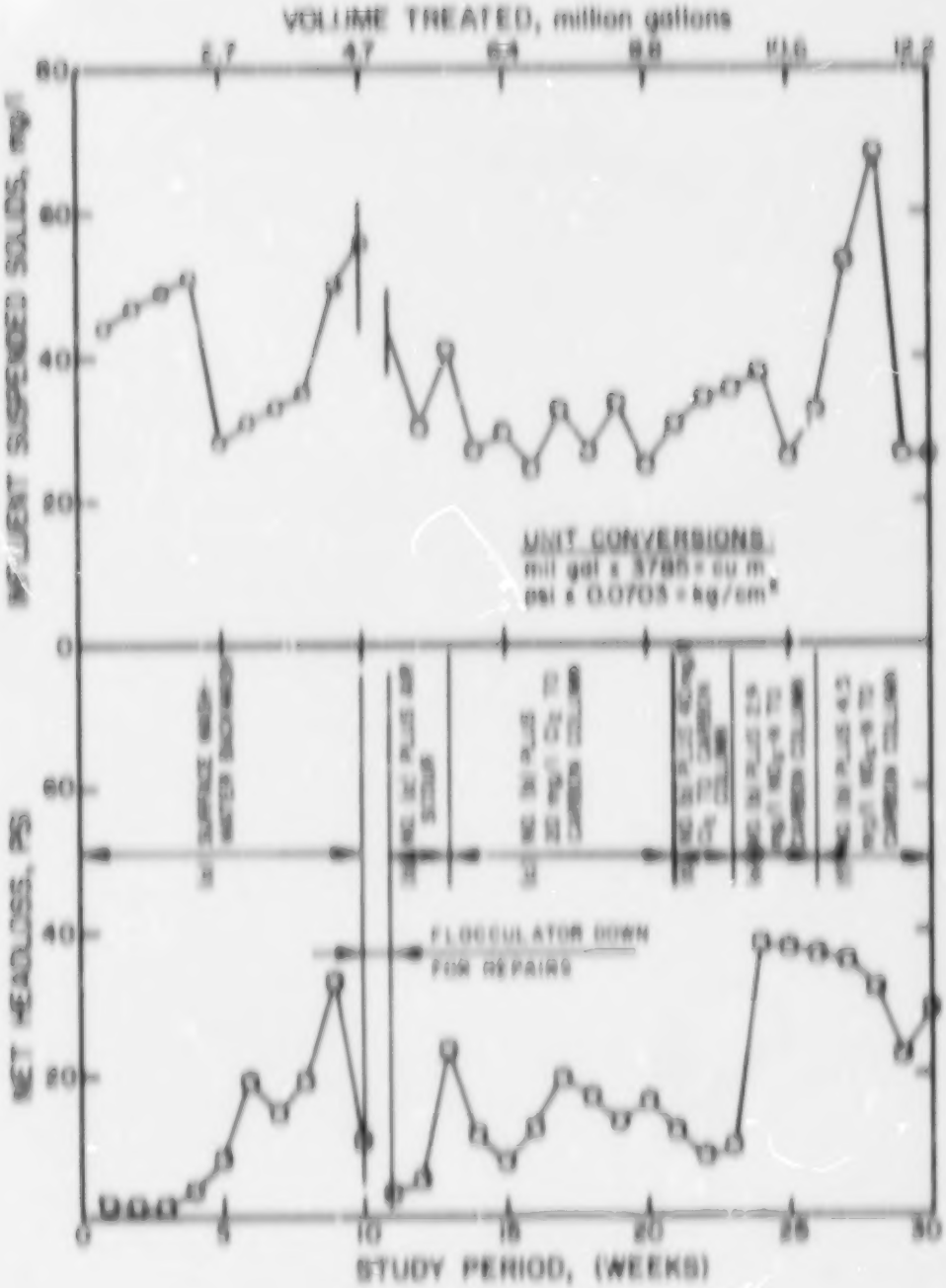
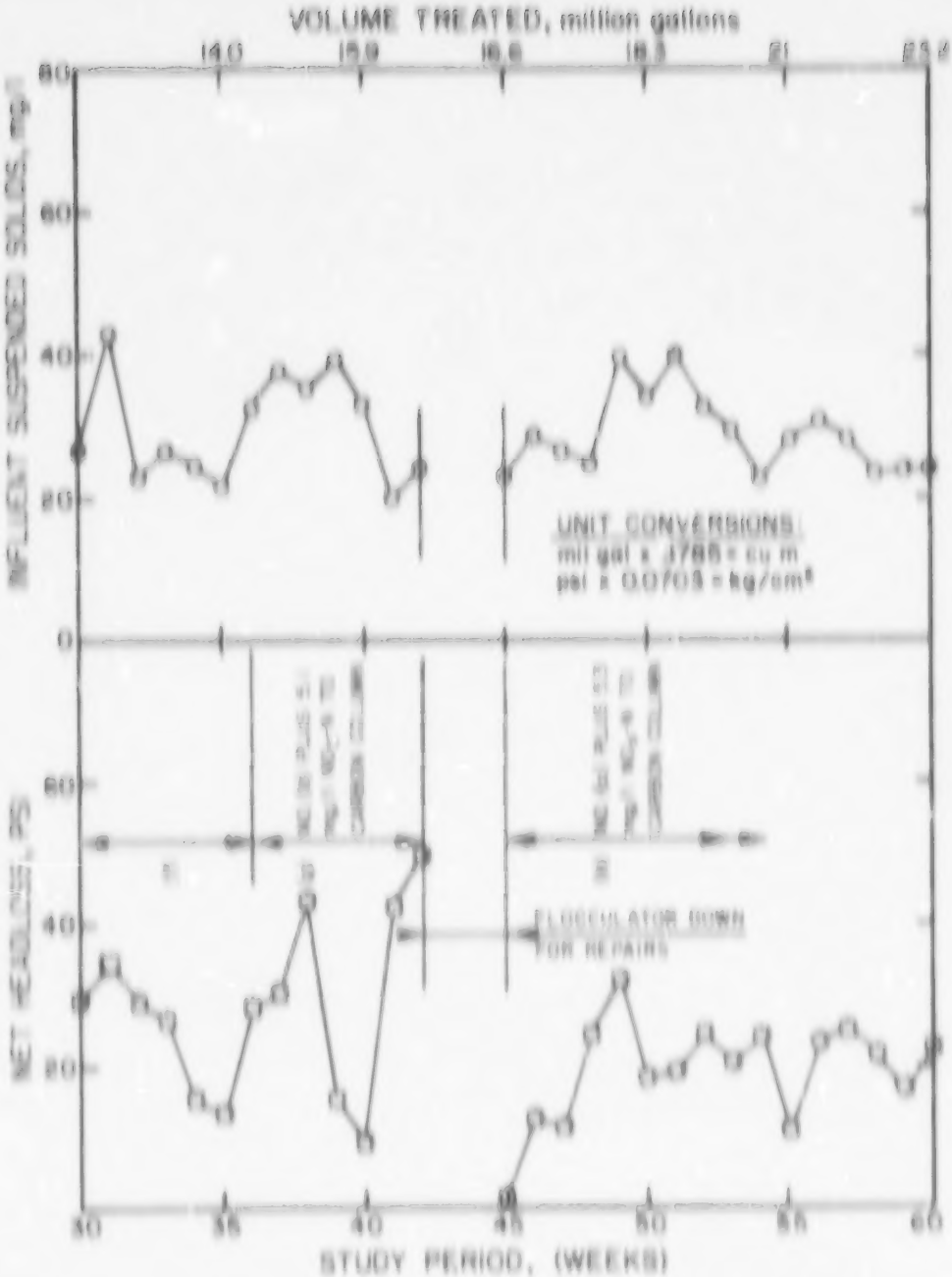


Figure 22. Carbon column suspended solids loading and pressure drop – first cycle.



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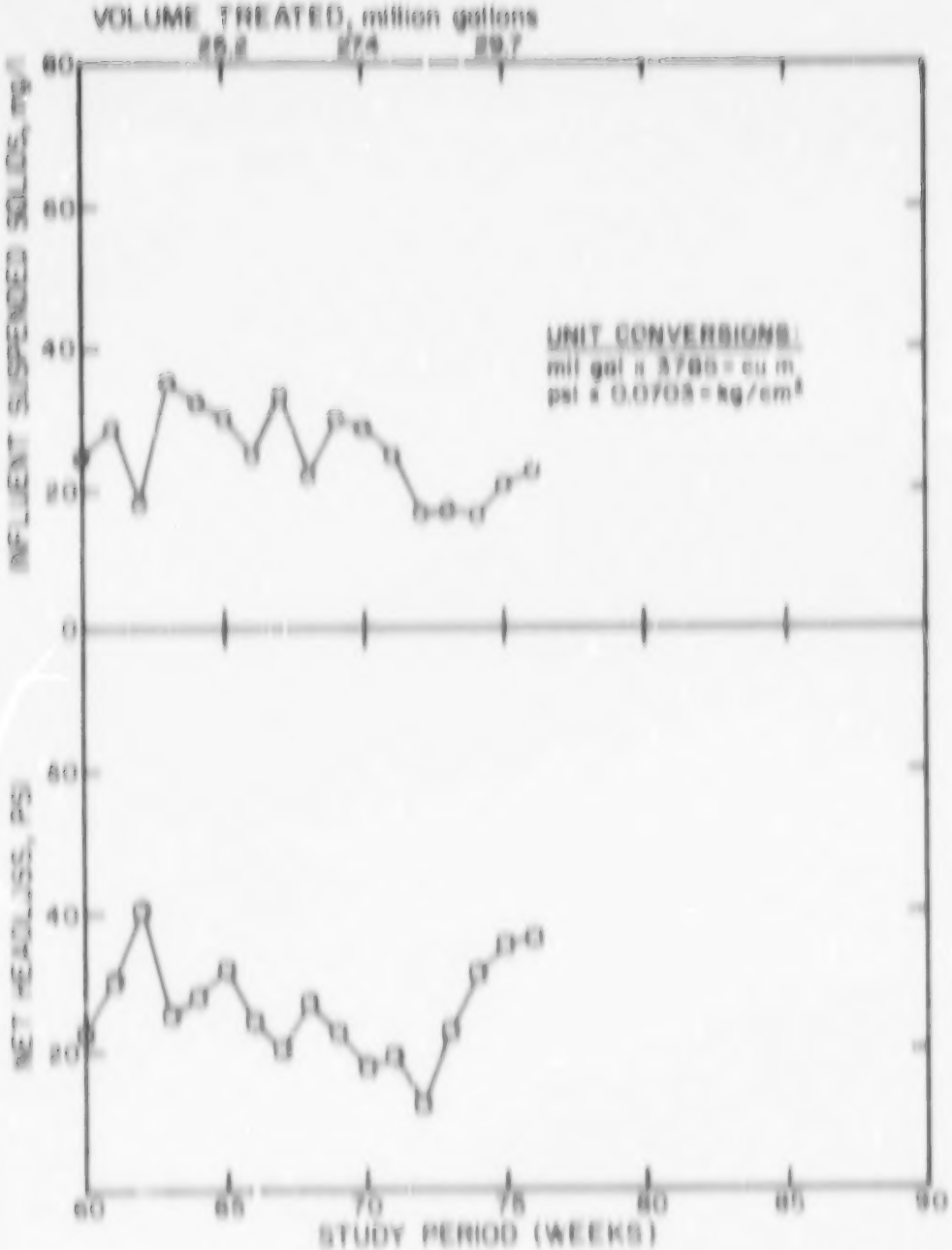

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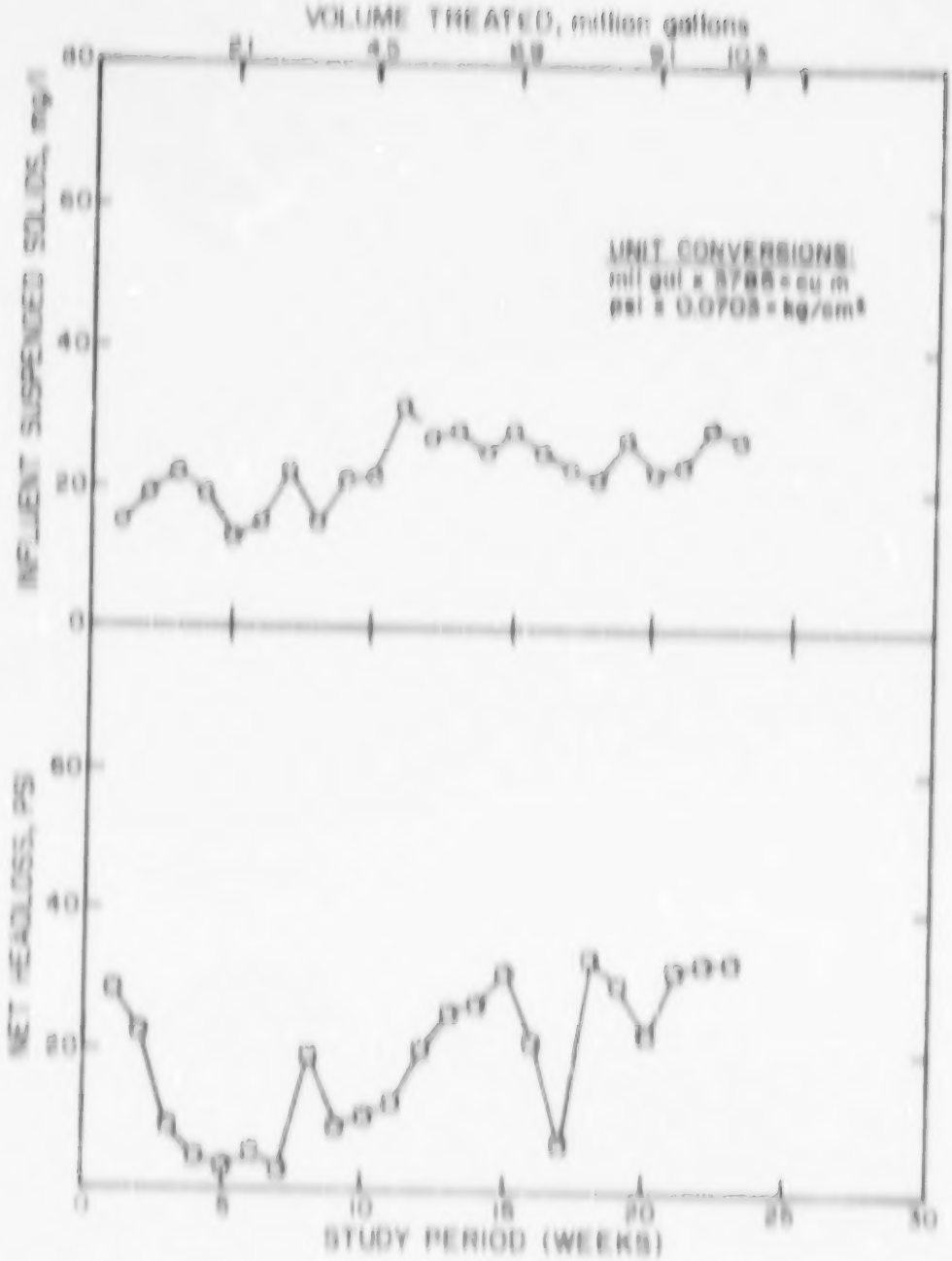


Figure 23. Carbon column suspended solids loading and pressure drop — second cycle.

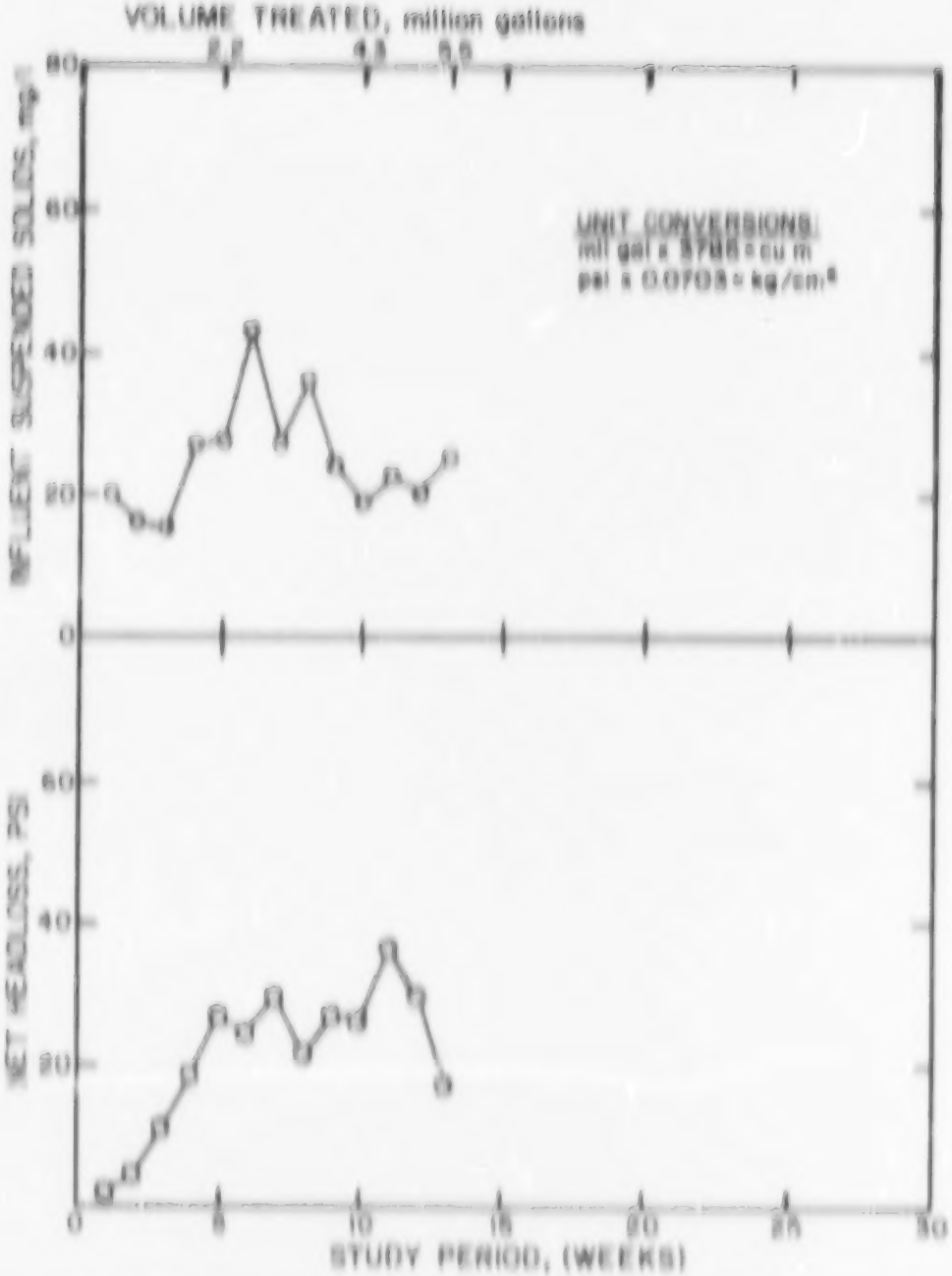


Figure 24. Carbon column suspended solids loading and pressure drop – third cycle.

was considerably less than the nominal wall thickness of 1.16 cm (1/8 in.). The supply line was replaced with thicker walled 1.04 stainless steel schedule 80 pipe and welded socket fittings were used to connect the rotary spray assembly to the supply line. In addition, a 5.08 cm x 5.08 cm x 0.64 cm (2 in. x 2 in. x 1/4 in.) angle iron coated with bitumastic coal tar epoxy was welded to the supply line for support.

During the three-week period (Dec. 27, 1972 to Jan. 17, 1973) when the column was off stream, the graded gravel layers over the Leopold blocks were removed to examine the underdrain system. The gravel layers were completely intermixed with carbon, probably due to the use of the auxiliary air scour during routine backwash. In examining the Leopold blocks, it was found that at two locations in the underdrain system the grout was dislodged leaving a gap of 3.18 to 6.35 cm (1/8 to 1/4 in.) wide by about 15.24 cm (6 in.) long between the filter blocks and the tank interior. The sudden surge of air during the air-water backwash procedure could have caused the dislodgement of the grout. Possibly, some carbon losses occurred through these openings and some losses also occurred during the backwash since carbon was found in the backwash water scavenger tank. The openings between the filter block and the tank interior were refilled with grout and a new 20.32 cm (8 in.) layer of graded gravel was placed over the filter blocks. When the column operation resumed on Jan. 17, 1973, the use of the air scour was terminated and the surface wash water backwash procedure was adopted until the completion of the study. In all subsequent periods, no sizeable carbon loss was observed.

Organic Removal and Effluent Quality

The major function of the carbon treatment step is the removal of soluble organic material from the chemically clarified raw sewage. In addition, substantial removal of organic suspended solids was expected as the packed bed of carbon served as a filter. In evaluating the column performance, the COD test was used as the primary parameter. The COD removal patterns for the three adsorption cycles are presented in Figures 25 through Figure 27. It is evident from the figures that the column removed a major portion of the influent COD both suspended and soluble.

The COD removal through the carbon column during the virgin adsorption cycle is presented in Figure 25. As the COD breakthrough curves show, the organic removal through the carbon column was excellent and remained practically constant throughout the entire cycle. The column treated 11,360 m (3.0 million gallons) of chemically clarified raw sewage before it was taken out of service for regeneration. It should be pointed out, however, that at the time the column was taken off-stream for regeneration, the carbon was still far from exhausted, based on the original regeneration criterion of an effluent COD of 40 mg/l. The decision to regenerate the carbon was based entirely on the need to obtain data on the effect of repeated thermal regenerations on the carbon performance and characteristics. In subsequent adsorption cycles, the column was regenerated after 3 to 5 months run with

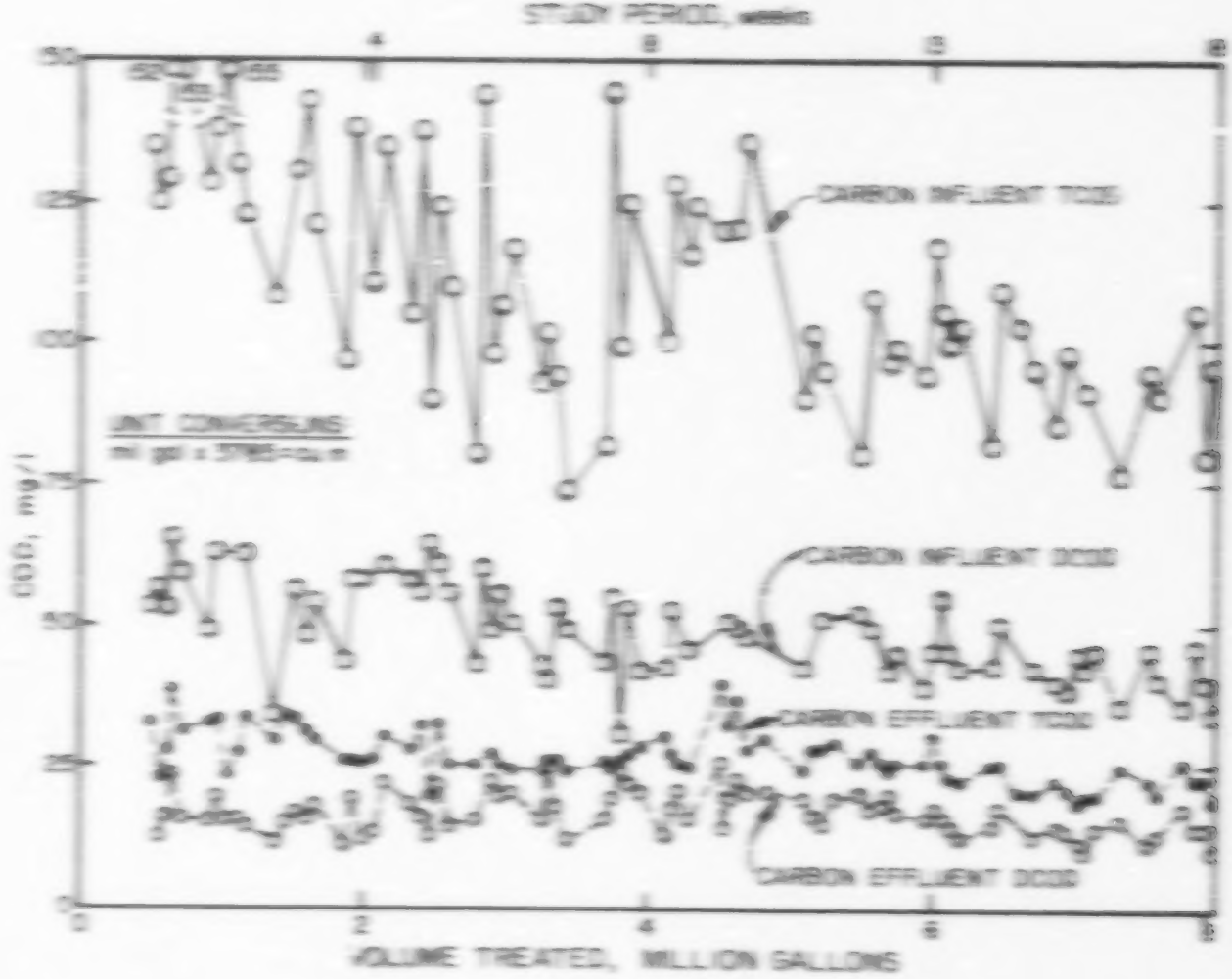
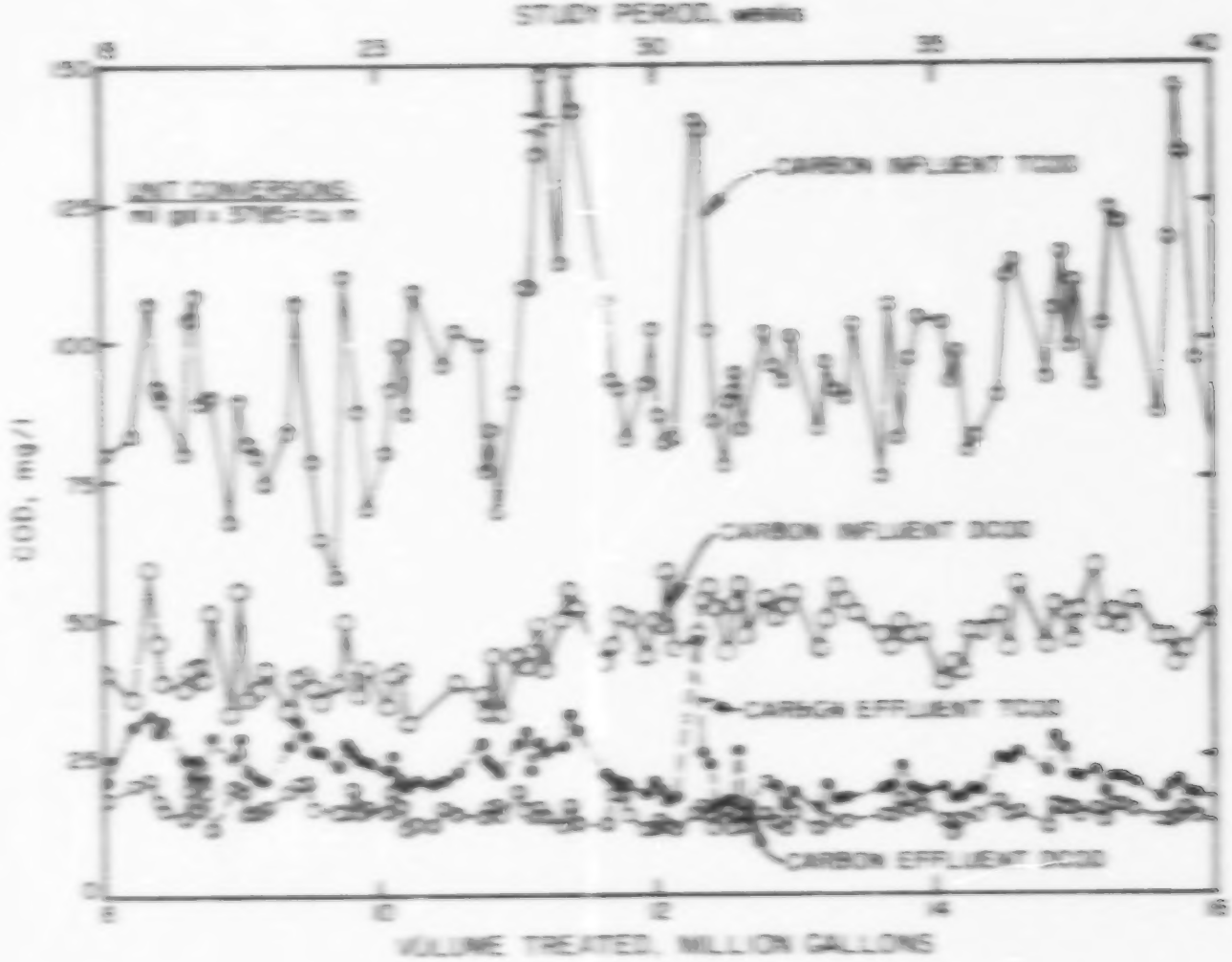


Figure 25. COD removal through the carbon column - first cycle.



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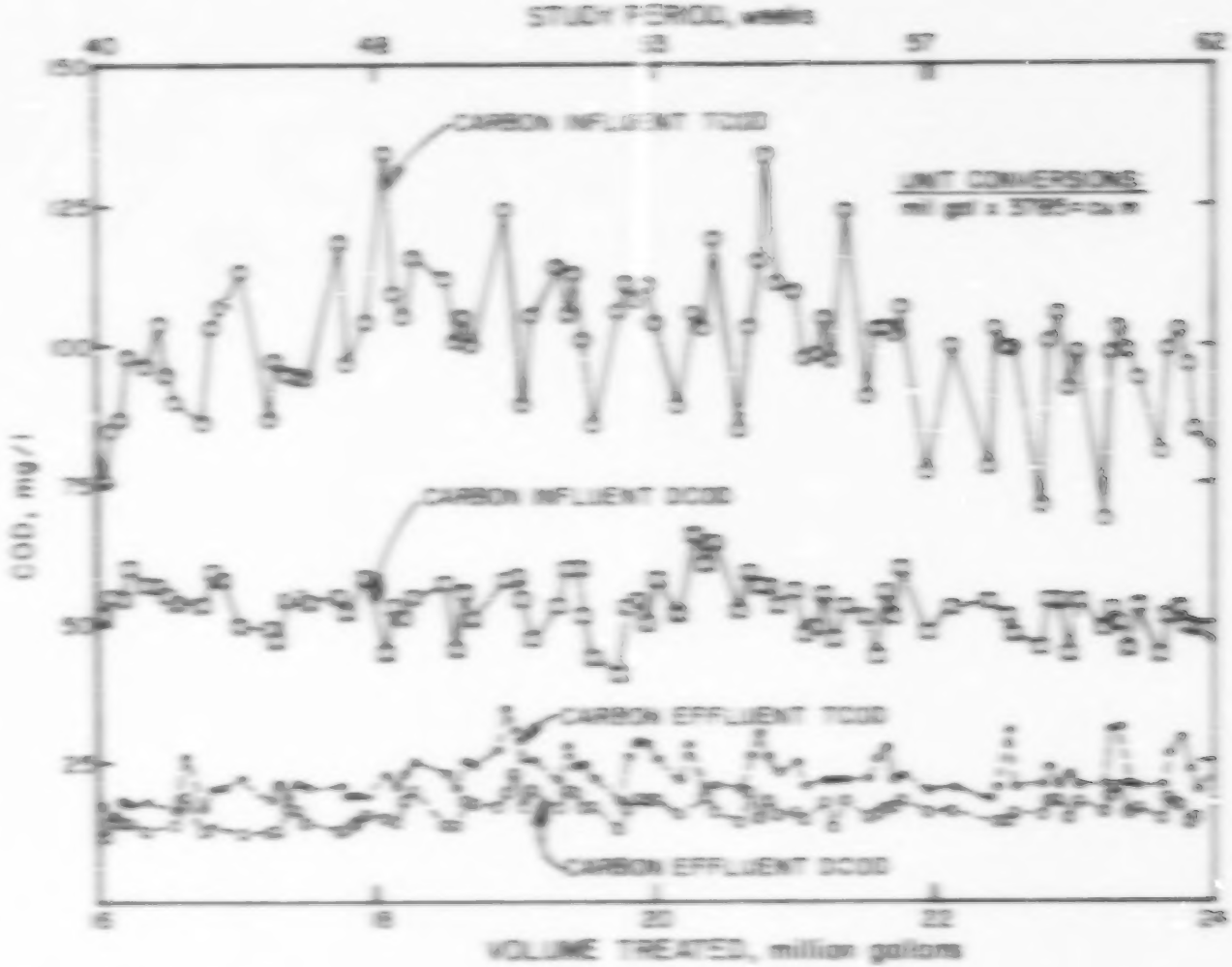
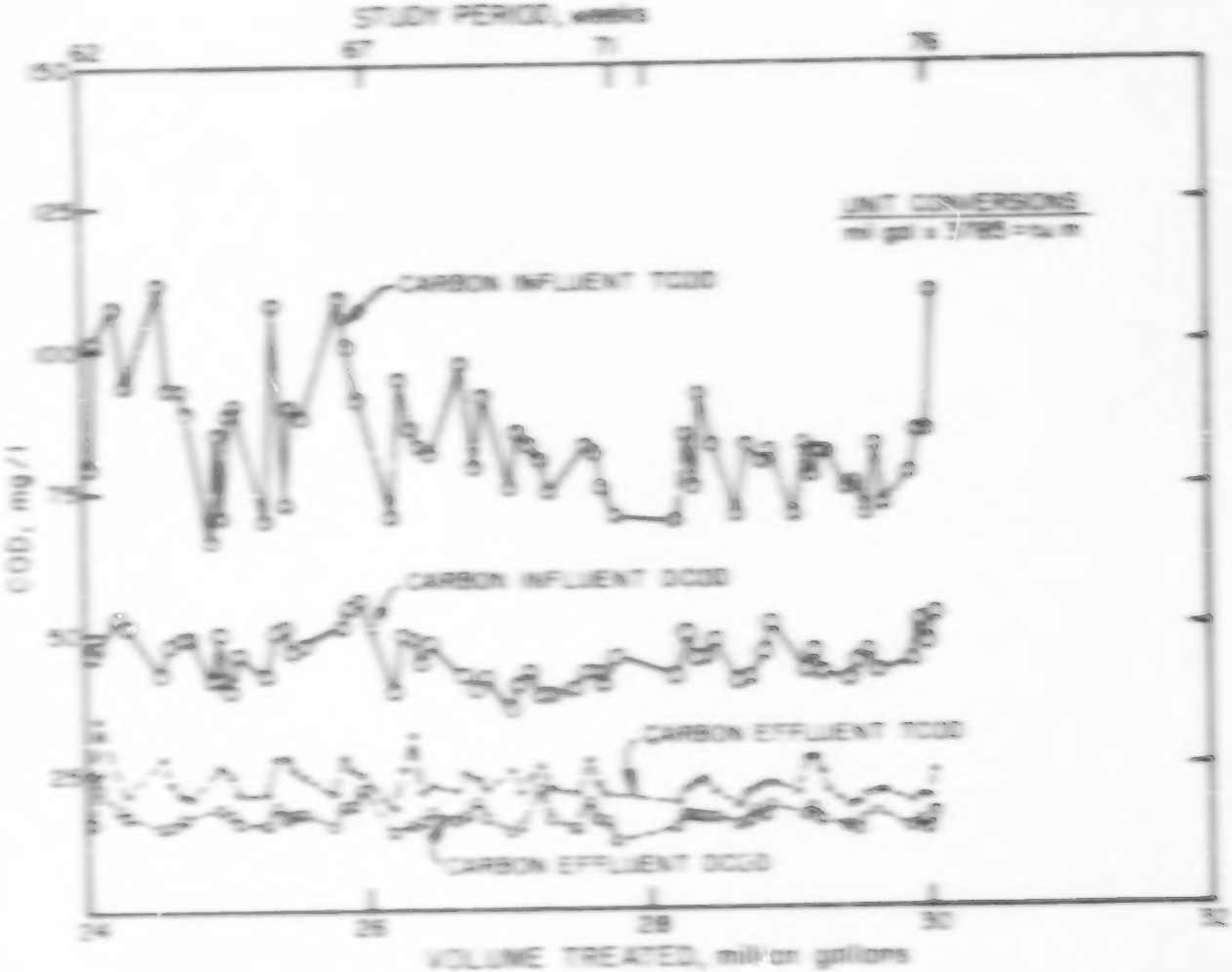


Figure 25. Continued



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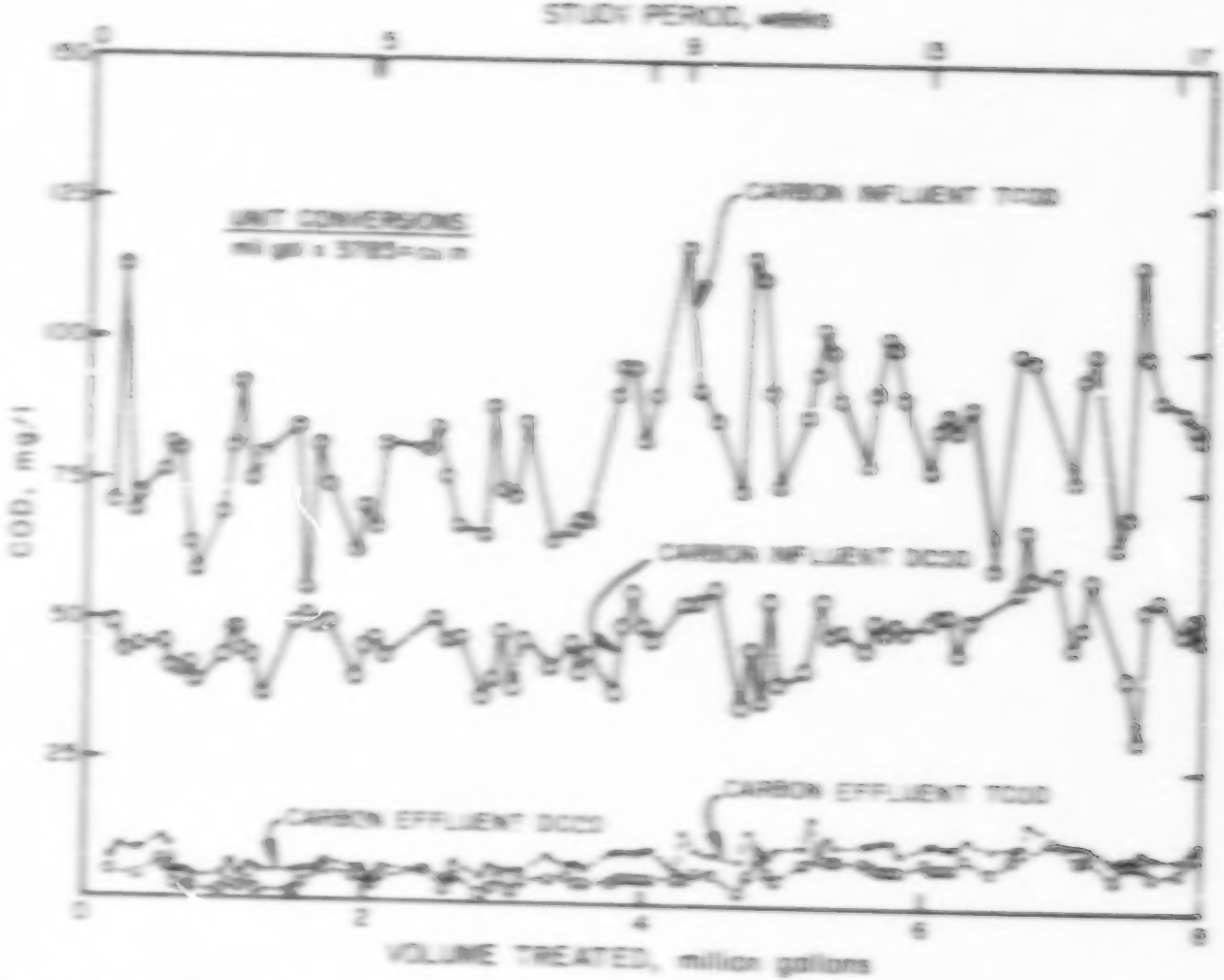

Figure 26. COD removal through the carbon column - second cycle.

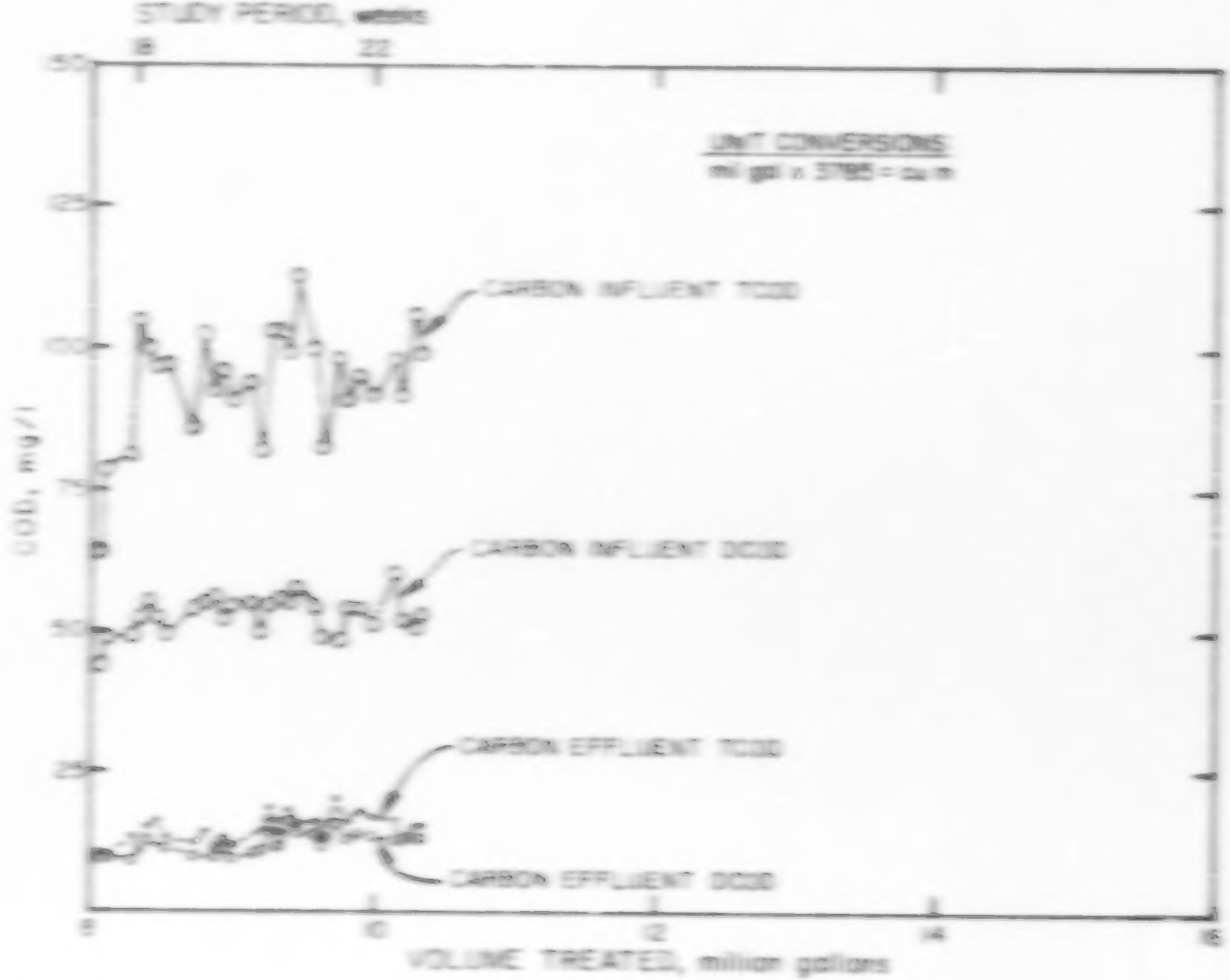

Figure 26 Continued

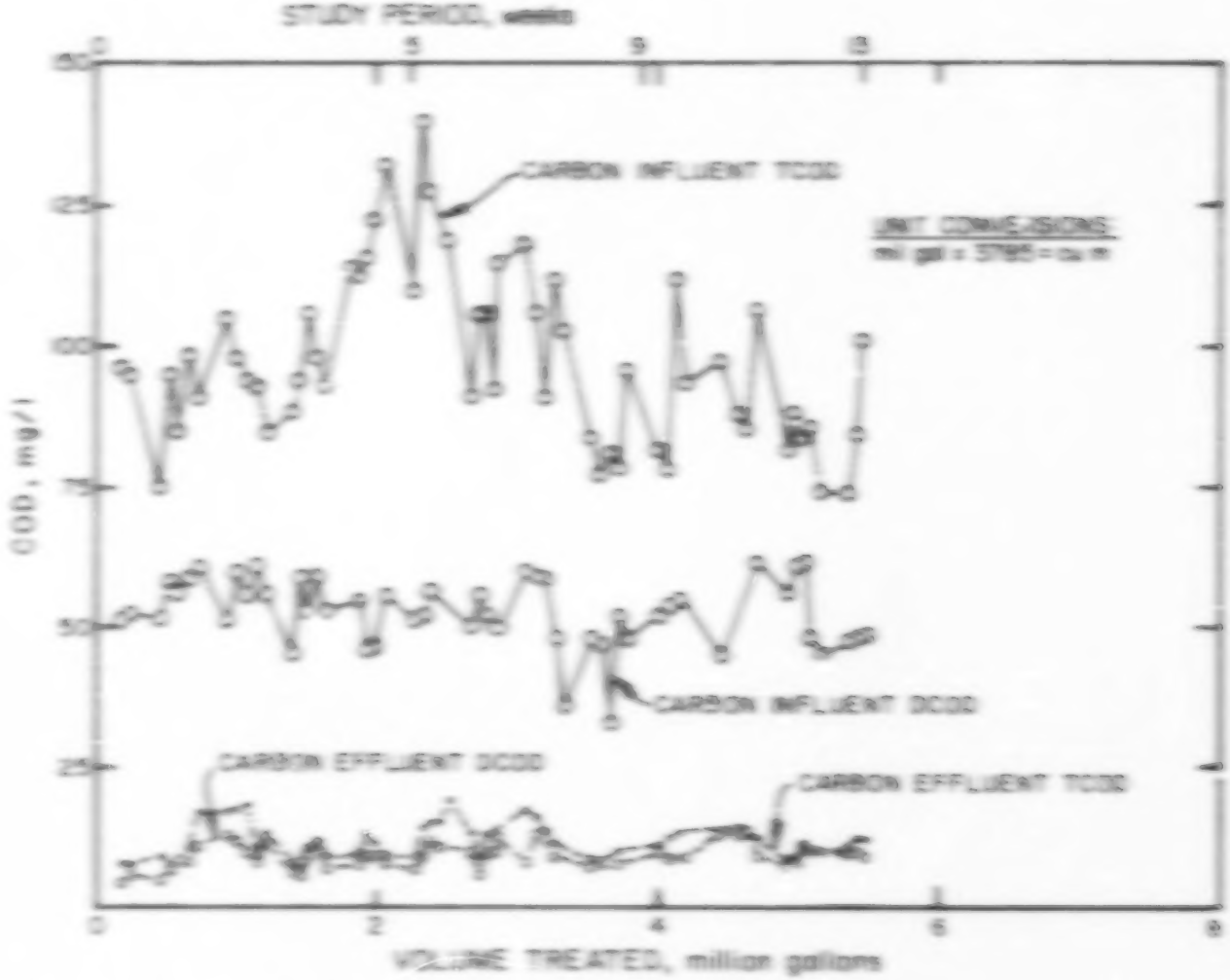

Figure 27. COD removal through the carbon column — third cycle.

out any regard to the state of exhaustion of the carbon. Based on the total throughput volume of 113,550 m^3 (30 million gallons) the carbon capacity during the virgin cycle was 3.5 kg TOD removed/kg carbon and 1.54 kg DOD removed/kg carbon. The corresponding carbon dosage was 0.021 kg carbon/m^3 (173 lbs carbon/mg).

The effect of repeated thermal regenerations on the DOD removal capacity at various levels of DOD applied is presented in Figure 29. As shown by the curves, the DOD removal capacity of the twice-regenerated carbon is predictably slightly less than that of the once-regenerated carbon. Moreover, it is also apparent from the curves that the regenerated carbon performance was unexpectedly much better than that of the virgin carbon. The observed higher DOD removal capacity of the regenerated carbon during the second and third adsorption cycles could be ascribed to enhanced biological activity resulting from continuous sodium nitrate addition to the carbon column. It should be pointed out that during the virgin adsorption cycle, sodium nitrate was not added to the carbon column until after 0.8 kg DOD/kg carbon was applied to the column. As Figure 28 shows, in subsequent periods following the nitrate addition, the DOD removal capacity of the virgin carbon improved significantly to such a degree as to parallel the DOD removal curves for the regenerated carbon. Figure 29 shows a plot of DOD removal in each cycle as a function of DOD applied. The data clearly show the improved organic removal performance during the second and third adsorption cycles and the favorable effect of nitrate addition on virgin carbon. These observations have significant economic impact in that continuous sodium nitrate addition to the column for sulfide control also enhanced the biological activity within the column, thereby increasing the apparent COD removal capacity of the carbon. With increased carbon capacity for organic removal, the carbon column could be operated for extended periods of times without regeneration and still maintain practically constant effluent quality. This was successfully demonstrated during the virgin adsorption cycle when the column effluent COD remained virtually unchanged through 113,550 m^3 (30 million gallons) of throughput volume. Thus, with higher carbon capacity or lower carbon dosage, the regeneration cost, both for initial capital investment and operation cost, would be proportionately lower.

For purposes of comparison, carbon capacity and TOD removal data from other IPC pilot plants are presented in Table 7 along with the first adsorption cycle data from the Fosoha study. The data clearly show the unusually high carbon capacity obtained at Fosoha. As previously discussed, this high carbon capacity has been attributed to the enhanced biological activity within the column resulting from continuous sodium nitrate addition.

Figure 30 presents the DOD removal profile through the carbon column at eight different cumulative throughput volumes during the virgin cycle. These wavefront data show that about 50 percent of the soluble organic material in the chemically clarified raw sewage was removed during the first

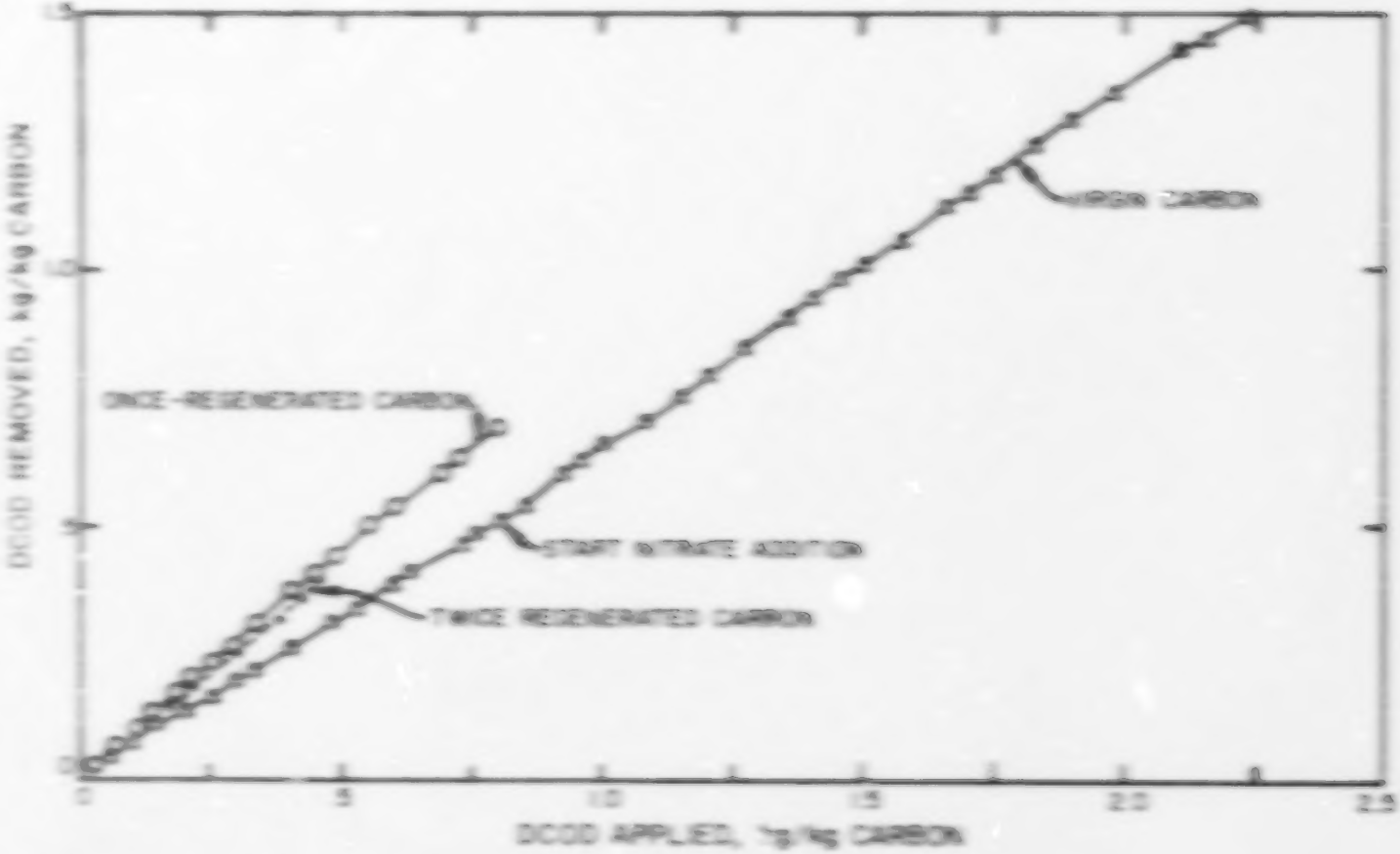

Figure 28 Effect of regeneration on DCOD removal capacity.

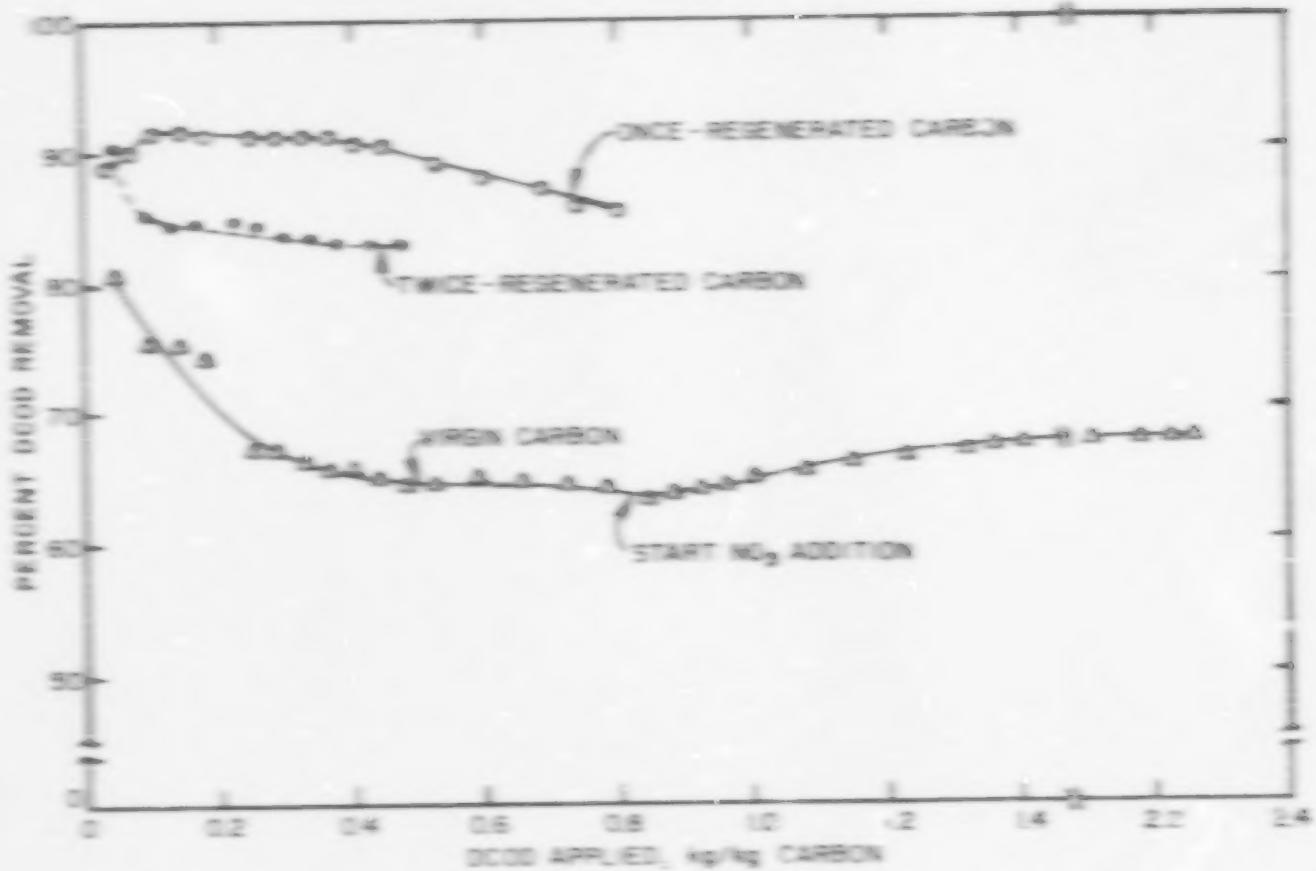

Figure 29. Effect of regeneration on percent DOCD removal.

TABLE 7. CARBON CAPACITY IN IPC PLANTS

Plants	TOD, mg/l		TOD Removal, %	Carbon Capacity, kg TOD removed/kg carbon
	Influent	Effluent		
Lebanon, Ohio	67	27	59.7	0.5
Blue Plains, Washington, D.C.	55	15	72.7	0.7
Ewing - Lawrence, N.J.	75	20	73.3	0.8
Pasco, California	98.4	23.6	76	3.5

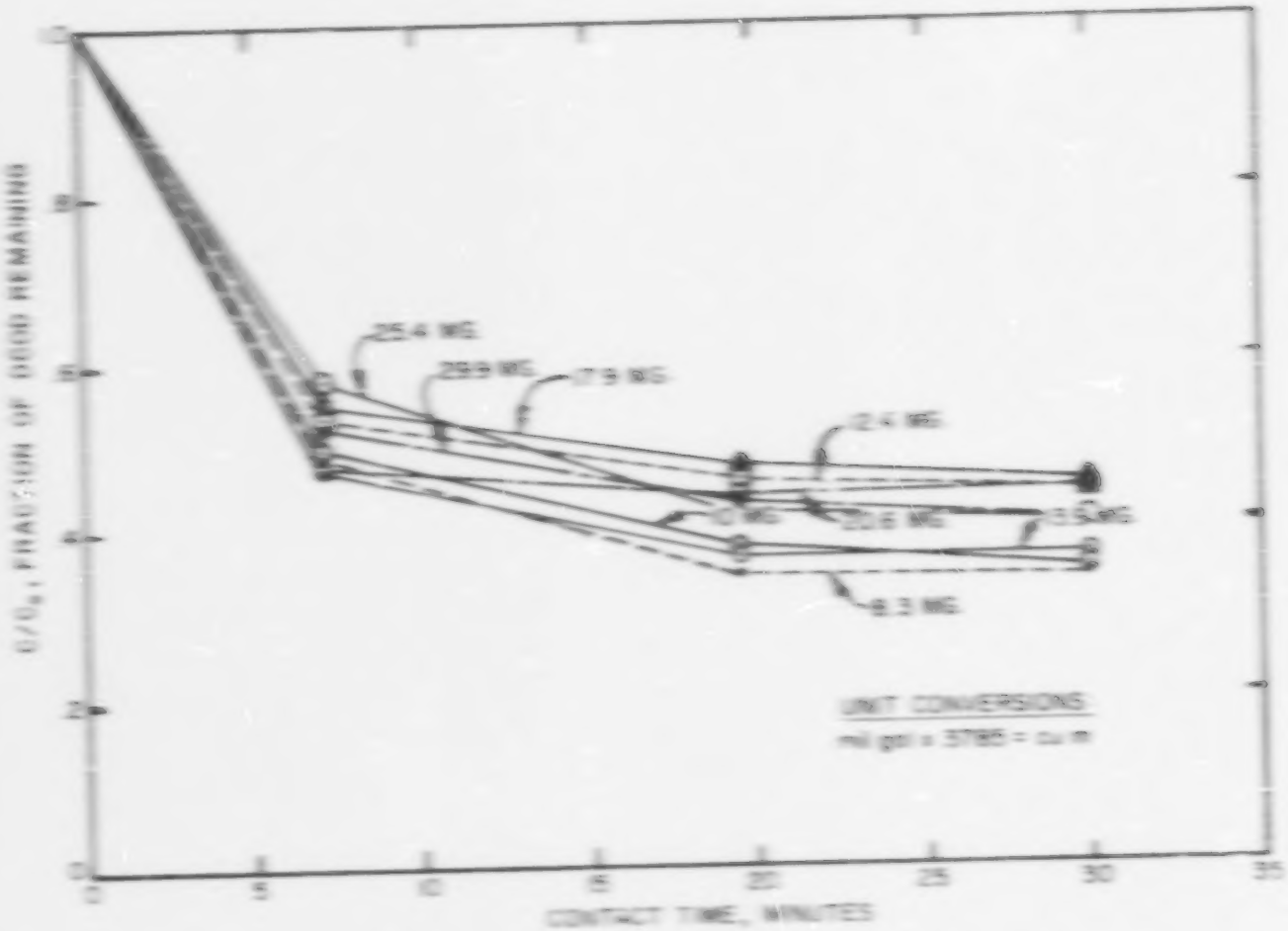

Figure 30. DOSE profile through the carbon column.

seven minutes of contact time. Although the DCOD removal increased with increasing contact time, it is evident from the curves that the soluble organics removal did not improve significantly beyond the 19.5 minutes contact time. Furthermore, the data show that over the 18.5 month period during which time the carbon processed about 113,550 m^3 (30 million gallons) of chemically clarified raw sewage, the carbon suffered only a slight decline in performance.

The turbidity and color removal patterns through the carbon column are shown in figures 31 through 33. As indicated in the figures, both the carbon effluent turbidity and color remained at low levels throughout the study. During the three adsorption cycles, the carbon column removed 72.5 percent of the turbidity and 61 percent of the color, thereby producing an effluent with an average turbidity of 6.3 JTU and an average color of 7.8. Table 8 presents a summary of the column performance for each of the three adsorption cycles.

These data all indicate a model for the performance of the granular carbon column in this study. It is theorized that the granular carbon column removes all the suspended organics applied through the mechanism of filtration. Removal of dissolved organics takes place by a combination of carbon adsorption and bacterial uptake. The bacterial metabolism of these organics both those adsorbed on carbon and those taken up by the bacteria leads to a demand for a hydrogen acceptor and production of new cells. These cells and the suspended organics are in effect wasted from the system during the backwash. The following calculation indicates that this theory has some validity. The average DCOD removal across the carbon column was 35.1 mg/l. The nitrate used was 5.4 mg/l as N or 18.5 mg/l as O. Since the DCOD which is not oxidized is synthesized, the cell production must be 35.1-18.5 = 16.6 mg/l as O or 16.6/1.42 = 11.7 mg/l VSS. Here 1.42 is the COD equivalent of the bacterial cell mass. This produces a sludge yield of 11.7/35.1 or 0.335 mg VSS per mg COD removed. This value is close to that reported for the synthesis yield in activated sludge denitrification systems (15). It is impossible to expect exact correlation because the SRT in a carbon column system is unknown.

CARBON REGENERATION RESULTS

Carbon Regeneration Process Control

The primary goal of carbon regeneration is to restore as much as possible the exhausted carbon it its virgin properties by effecting maximum removal of the adsorbed impurities from the pores of the spent carbon with a minimum damage to the basic pore structure. Thus, during regeneration the furnace operating variables such as temperature, carbon feed rate and steam feed rate are closely controlled. Moreover, several laboratory control tests, such as the tests for apparent density, iodine number and molasses number are performed in the course of regeneration to monitor the quality of the regenerated carbon.

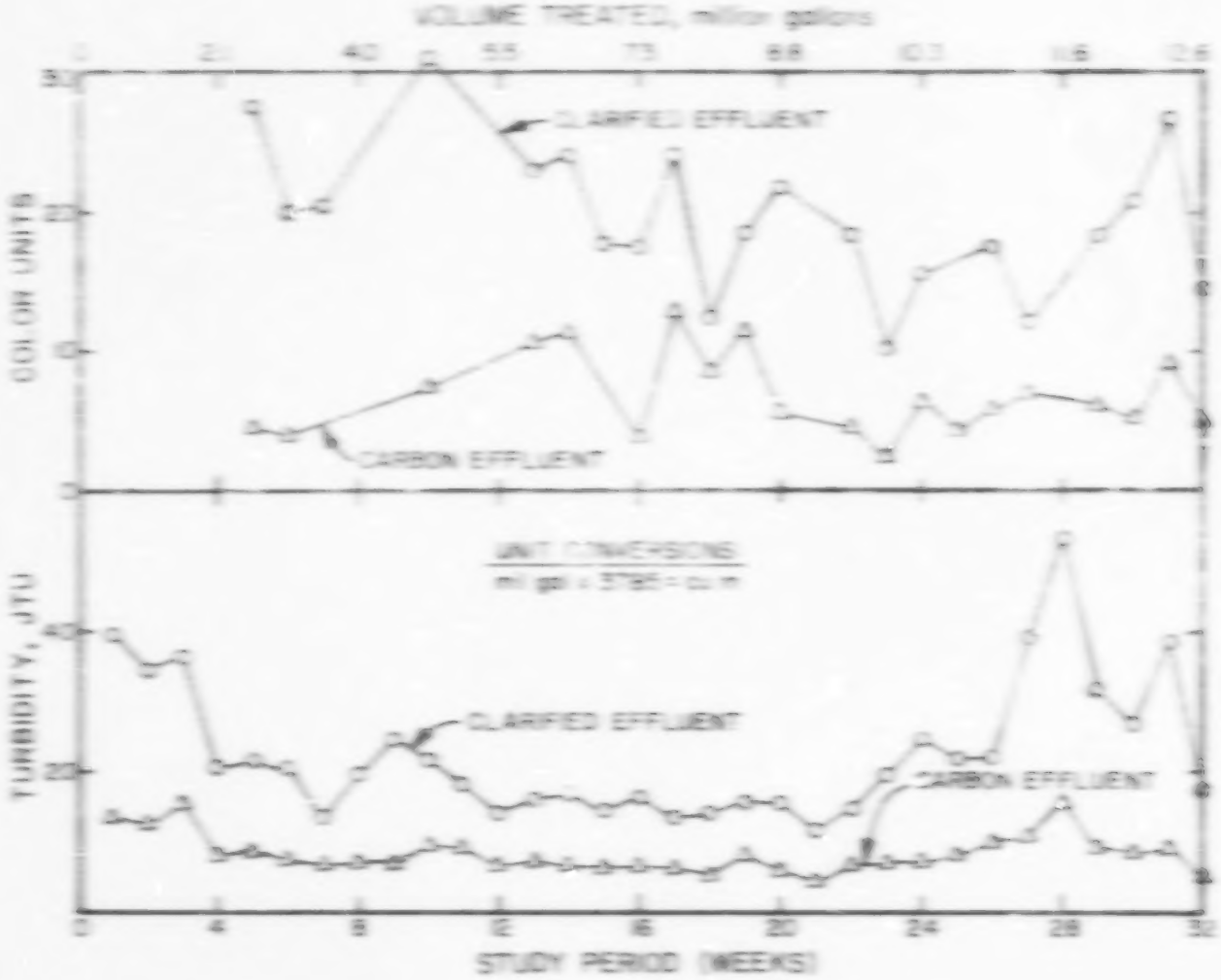

Figure 3. Turbidity and color removal through the carbon column - first cycle

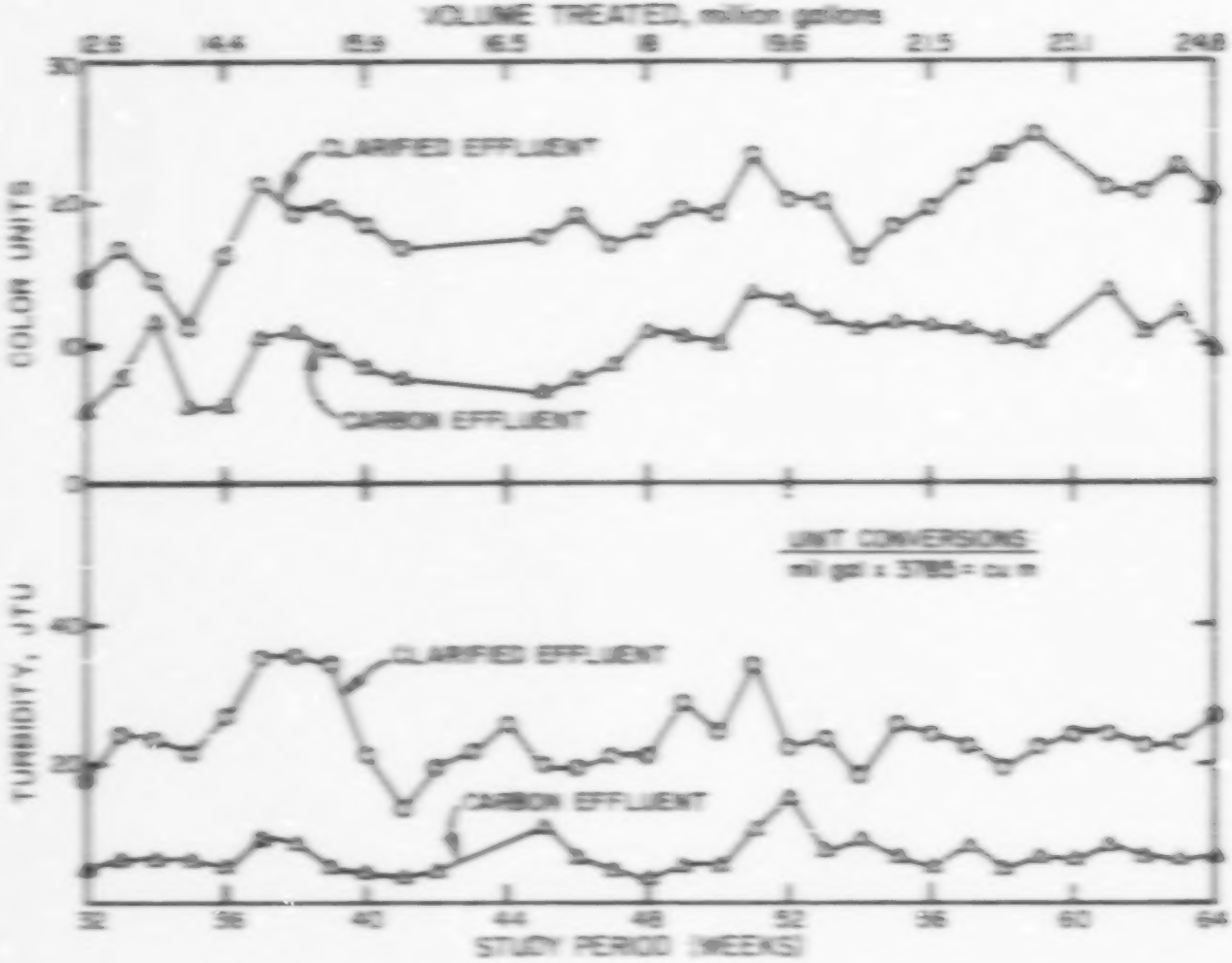

Figure 31. Continued

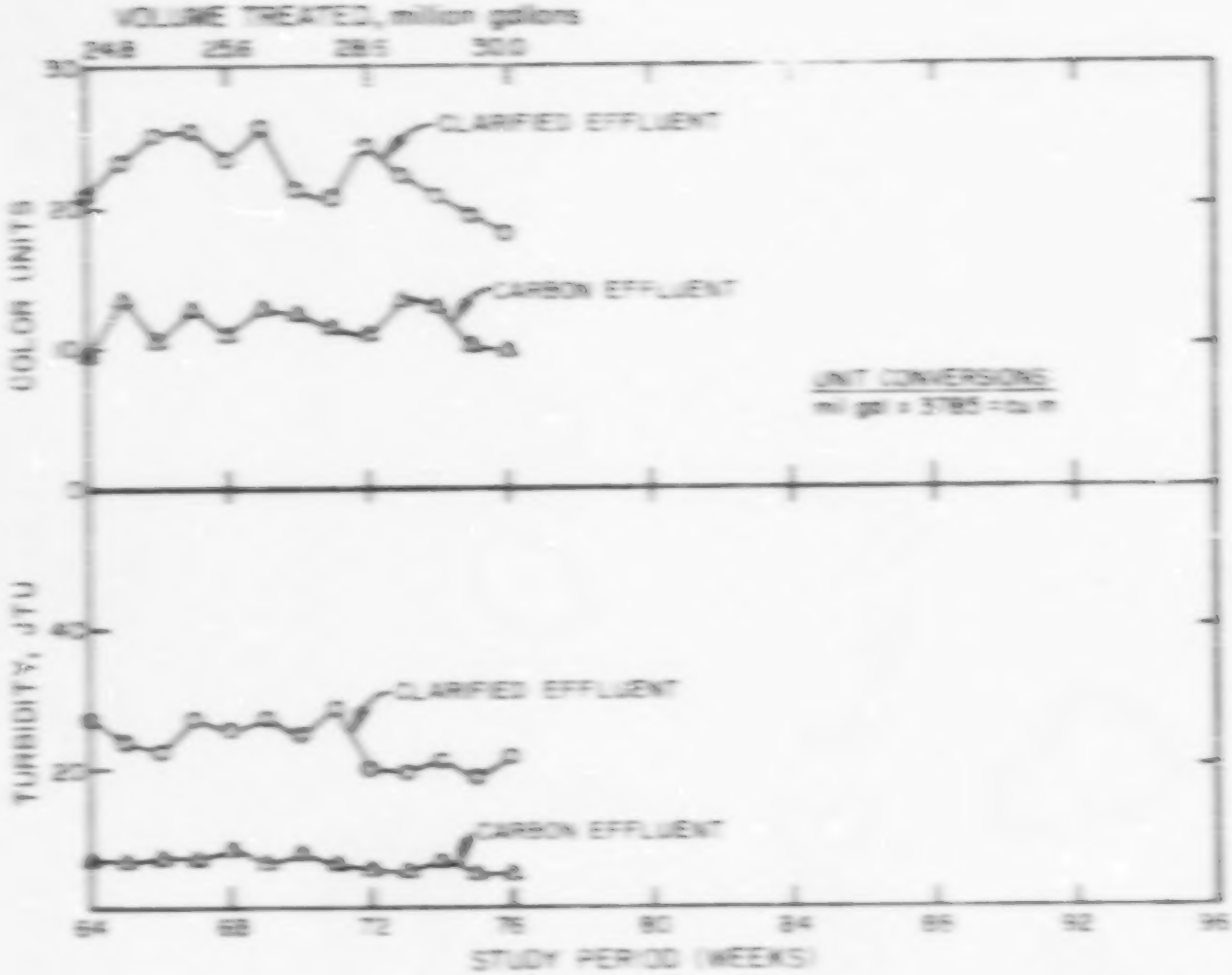

Figure 31 Continued

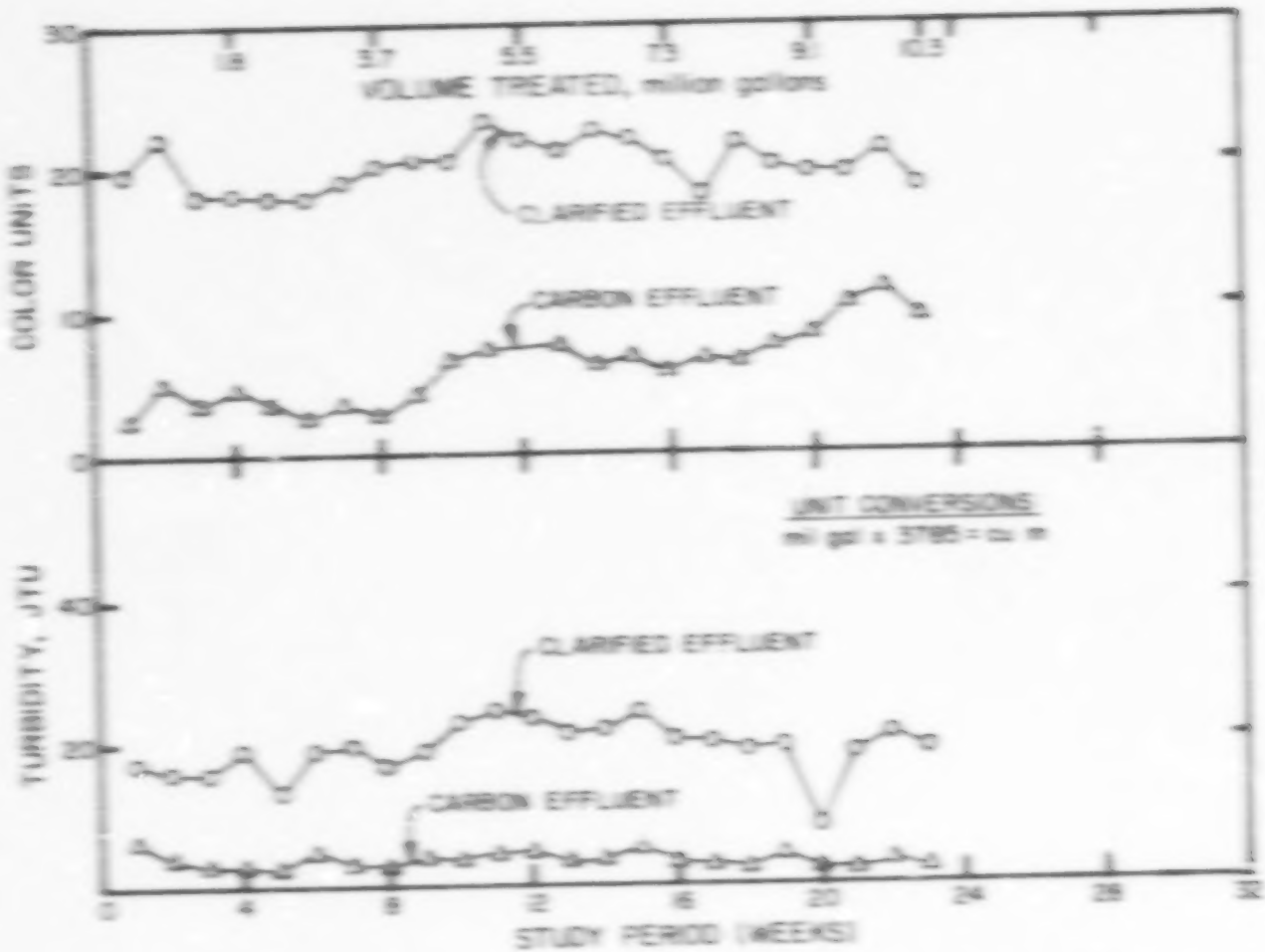

Figure 32. Turbidity and color removal through the carbon column- second cycle

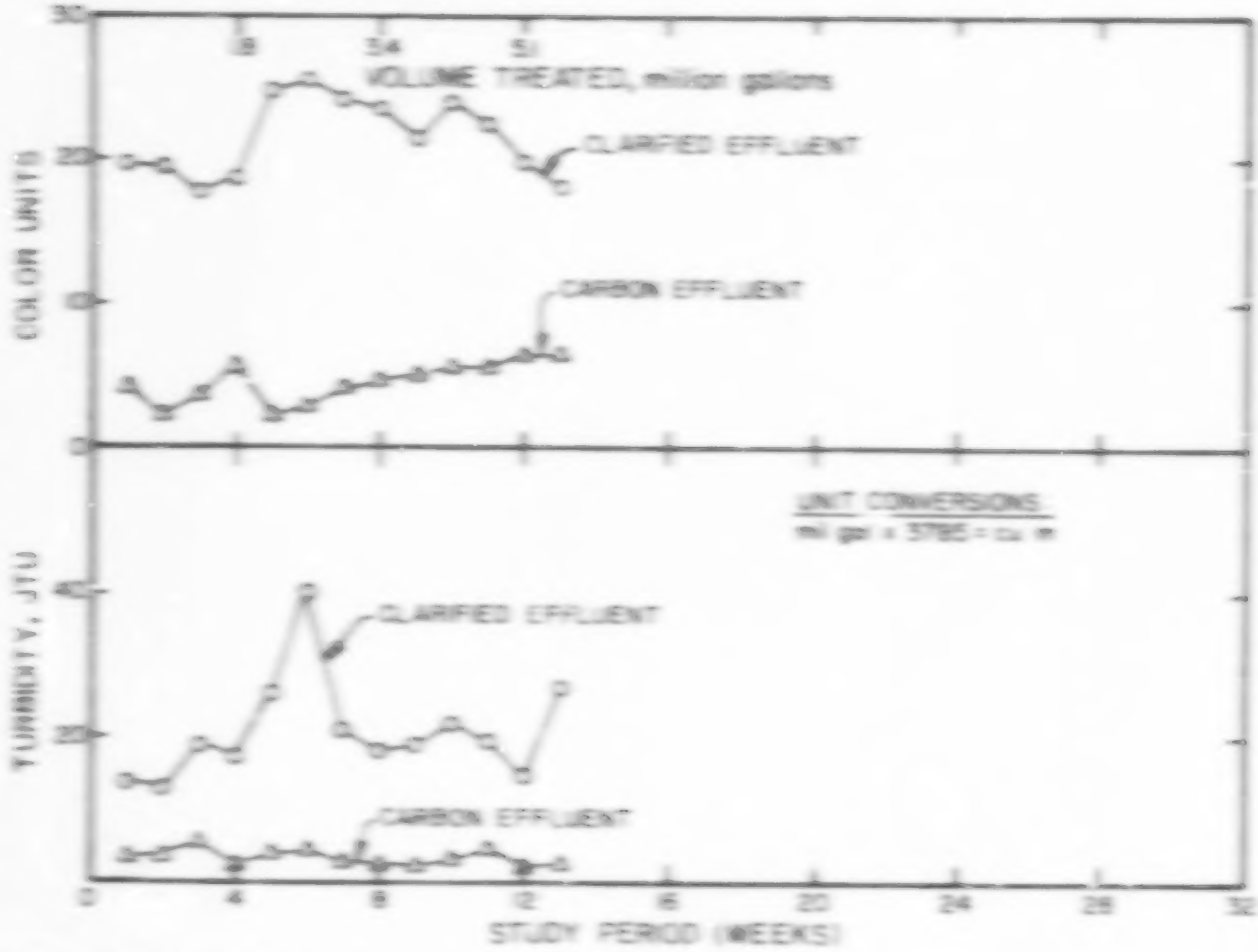

Figure 33. Turbidity and color removal through the carbon column – third cycle.

TABLE 8. CARBON COLUMN PERFORMANCE

Parameters	Adsorption Cycles			Overall Averages
	1	2	3	
Total COD:				
Influent, mg/l	98.4	86.2	98.2	95.0
Effluent, mg/l	23.6	10.0	11.5	19.3
Removal, %	76.0	89.4	86.3	79.9
Dissolved COD:				
Influent, mg/l	48.0	48.4	52.1	48.6
Effluent, mg/l	16.1	7.2	9.4	13.5
Removal, %	66.5	85.1	81.9	72.2
Color:				
Influent, color units	19.2	20.4	21.6	20.0
Effluent, color units	9.8	6.0	4.7	7.8
Removal, %	49.0	70.6	78.2	61.0
Suspended Solids:				
Influent, mg/l	30.9	22.8	28.5	28.2
Effluent, mg/l	8.3	4.0	3.8	7.7
Removal, %	73.1	82.5	84.5	73.3
Turbidity:				
Influent, JTU	24.4	19.9	20.6	22.9
Effluent, JTU	7.7	3.8	3.6	6.3
Removal, %	69.4	80.9	82.5	72.5

The apparent density test was used as the primary control test during regeneration with the decolorizing tests for iodine and molasses numbers used as supplemental control tests. The apparent density, which usually ranged from 0.48 to 0.49 g/cm^3 for virgin carbon, increased to about 0.59 to 0.61 g/cm^3 when the carbon becomes exhausted. When the spent carbon is properly regenerated, most of the adsorbed impurities are removed thus restoring the apparent density to the virgin level.

During regeneration, the apparent density test was determined routinely every hour whereas the tests for iodine and molasses numbers were performed every 4 and 2 hours, respectively. The hourly samples of regenerated and quenched carbon were composited over the regeneration period and analyzed along with the spent carbon composite sample for apparent density, iodine number, molasses number, methylene blue number, ash content, and particle size distribution.

Effect of Regeneration on Carbon Properties

As a result of thermal regeneration, some losses inevitably occur both in the carbon adsorptive capacity and the carbon quantity. These losses are of economic importance since they constitute a significant portion of the carbon regeneration cost. The carbon loss during the three regeneration cycles varied from 2.5 to 6 percent. In this report, the carbon loss is defined as the difference in the carbon volume in the contactor just before transfer to the drain bin and just after backwash of the regenerated carbon. The carbon loss can be ascribed either to the direct oxidation of the exterior surfaces of the carbon granules by the activating gases and/or to the normal handling attrition if the basic carbon structure had been previously weakened by internal over-activation [1].

The complete removal of adsorbed organics from the carbon pores is actually never attained during regeneration. In addition to ash buildup in the carbon pores, some of the carbon granules are unavoidably burned with the adsorbate thereby reducing further the total surface area available for adsorption. Consequently, with the physical loss of carbon during regeneration is the attendant decrease in the adsorptive capacity as measured by DCOD reversal, iodine number and molasses number.

The changes in some of the physical properties of the carbon before and after regeneration are shown in Table 9. It is apparent from the data that repeated thermal regeneration had the effect of decreasing the iodine number and increasing the ash content. The iodine number, which relates to the surface area of pores larger than 10 A^0 diameter, was used in this study as an index to measure the extent to which the carbon micropores were cleared of adsorbate during regeneration. As indicated by the data in Table 9, the iodine number decreased about 26 percent from a virgin level of 1040 to 773 mg/g after three adsorptive cycles. The ash content of the carbon, which measures the amount of calcium and other inorganic residues picked up by the carbon during service increased about 67 percent from a virgin level of 6.4 to 10.7 percent after the first regeneration. On the

| | | |

TABLE 10. FURNACE OPERATING CONDITIONS DURING IVC CARBON REGENERATION

Parameters			Regeneration Number		
			1	2	3
Duration of Regeneration, hours			53	84	60
Furnace Loading, kg carbon/hr (lb/hr)			41.4 (91.1)	34.8 (76.6)	36.3 (80.3)
Steam Used, kg/kg carbon			0.59	0.60	0.67
Fuel Used kJ/kg Carbon (BTU/lb Carbon)	Furnace		8427 (3625)	10,288 (4332)	7184 (3090)
	Afterburner		7329 (3149)	12,571 (5408)	9364 (4194)
	Total		15,756 (6769)	22,860 (9735)	16,548 (7280)
Average Temp. °C (°F)	Hearth Number	1	367 (693)	338 (640)	327 (635)
		2	485 (905)	472 (876)	489 (840)
		3	596 (1108)	590 (1095)	558 (1037)
		4	935 (1689)	901 (1652)	896 (1646)
		5	875 (1788)	936 (1717)	942 (1728)
		6	958 (1760)	954 (1750)	946 (1740)
	Afterburner		741 (1365)	726 (1339)	774 (1425)
Carbon Loss, %			2.9	6	4.4

Air Pollution Control System Performance

The flue gases discharged from the top hearth of the multi-hearth furnace contained both particulate and obnoxious-smelling substances. These air pollutants were controlled through an air pollution control system consisting of a baghouse for particulate removal and an afterburner, operated in series with the baghouse for odor control. The afterburner was operated at a temperature range of 719°C (1326°F) to 741°C (1368°F). The baghouse was operated at a temperature ranging from 149°C (300°F) to 163°C (325°F). While it is advantageous to maintain a high temperature in the baghouse to prevent condensation problems, due precaution had to be exercised to prevent the temperature from rising to within 10°C (50°F) to 38°C (100°C) of the critical temperature of the fabric filter. Thus, to minimize the danger of burning the filter bags, the baghouse inlet was equipped with a valved side connection for dilution air addition. Under normal furnace operating conditions, the dilution air inlet valve was maintained in a closed position. However, when the baghouse temperature increased beyond 163°C (325°F), which could have been triggered by a disruption of the carbon feed rate and/or plugging of the quench tank screen, the dilution air valve was manually opened for such a duration as needed to restore the temperature to about 163°C (325°F).

During the first carbon regeneration, the performance of the various components of the air pollution control system was evaluated by test engineers from a local testing laboratory. In evaluating the system, the flue gases at the inlet and outlet of the baghouse and at the outlet of the afterburner were tested for flow rate, temperature, particulate matter, volatile hydrocarbons, oxygen, carbon dioxide, carbon monoxide, water vapor, oxides of nitrogen, and oxides of sulfur. The odor number was determined on the integrated flue gas samples collected in 8.2-liter cylinders at the inlet to the baghouse and at the outlet of the afterburner.

Gas flow measurements were made with a standard pitot tube and a magnehelic draft gauge. Temperatures were measured with a Chromel-Alumel thermocouple and a portable potentiometer. The test for particulate matter was performed using a wet impingement method. Samples for the determination of oxides of sulfur were collected by an impinger train containing hydrogen peroxide. An Orsat analysis was performed to determine the carbon dioxide and oxygen concentrations. The phenol-disulfonic acid method was employed for the determination of the oxides of nitrogen. A gas-chromatograph-combustion-infrared technique was used to determine the concentration of carbon monoxide and volatile hydrocarbons.

During regeneration, odors were detected and this was confirmed by the relatively high odor number of 3 odor units/l (90 odor units/SCF). Particulate emission was also high and averaged 0.30 kg/hr (0.64 lb/hr). Based on the particulate emission rate data, the baghouse removed only about 76 percent of the incoming dust load, which was indeed significantly below the

design removal efficiency of 99 percent. It should be pointed out, however, that the emission data represented samples collected over 45 to 60 minutes sampling period. The total actual weight of dust collected from the baghouse over the 53-hour regeneration period was only 14.7 Kg (32.5 lbs.), which represented about 56 percent of the calculated dust removed.

In Table II is presented a summary of the emission data from the various components of the air pollution control system. For purposes of comparison, the emission data obtained during the third regeneration of the lead contactor of the tertiary two-stage carbon adsorption system is also included in this table. It is apparent from the data in Table II that the emission parameters evaluated were significantly higher in the IPC carbon regeneration than in the carbon column III 3A. This observation was expected, considering that the IPC carbon column was subjected to a much heavier load of organic matter than column III 3A. At the time the IPC column was taken off-stream for regeneration, it had processed 113,550 m^3 (30 million gallons) of alum-polymer treated raw sewage with an equivalent total organic loading of 4.6 kg TCOD applied/kg carbon and 2.3 kg DCOD applied/kg carbon. The corresponding carbon capacity in the virgin cycle was 3.54 kg TCOD removed/kg carbon and 1.54 kg DCOD removed/kg carbon. On the other hand, when column III 3A was regenerated it had treated 108,000 m^3 (28.48 million gallons) of activated sludge plant effluent with a total applied organic loading of 1.0 kg TCOD/kg carbon and 0.65 kg DCOD/kg carbon. The COD removal capacity was .65 kg TCOD/kg carbon and .29 kg DCOD/kg carbon. The results of the air pollution control system evaluation thus demonstrate that, the air pollutants eventually discharged to the atmosphere during carbon regeneration, depend on the amount and composition of the adsorbate.

DISCUSSION OF THE IPC SYSTEM PERFORMANCE

As discussed in previous sections the chemical clarification step provided the major bulk of the pollutant's removal in the IPC system. In addition to the anticipated high degree of suspended solids and phosphate removal, significant removal of suspended organic material was obtained. The dissolved organic removal, however, which was measured by DCOD was only marginal, indicating that the alum-polymer treatment was not effective in the coagulation of impurities in the wastewater filterable through a 0.45u filter used in the DCOD determination. This observation is contrary to what other investigators (3,12) reported, which suggests that the type of wastewater treated affects the degree of soluble organics removal by the chemical clarification process.

The chemical clarification of raw sewage using alum at an average dosage of 25 mg/l Al (275 mg/l alum) with 0.3 mg/l of anionic polymer (Catgon WT-3000) was very effective throughout the study in producing good quality clarified effluent. The clarified effluent had an average turbidity, suspended solids and TCOD concentration of 22.9 JTU, 28.3 mg/l and 95.8 mg/l, respectively. The total phosphate in the raw sewage, which had averaged 11.1 mg/l P was reduced about 88 percent, resulting in a clarified effluent with an average total phosphate concentration of 1.3 mg/l P.

The economics of any chemical clarification system is influenced a great deal by the cost involved in the treatment and subsequent disposal

TABLE 11. SUMMARY OF AIR POLLUTION CONTROL SYSTEM PERFORMANCE

Parameters	APCD Emission Limit	1st Regeneration of IPC Carbon Column			3rd Regeneration of Two-Stage Carbon Column (III 3A)		
		Baghouse Inlet	Baghouse Outlet	Afterburner Outlet	Baghouse Inlet	Baghouse Outlet	Afterburner Outlet
1. Particulate Matter							
Concentration, mg/l	0.46	7.82	3.57	0.48	4.16	1.08	0.077
Emission Rate, kg/hr	6.45	2.11	1.44	0.30	0.98	0.36	0.11
2. Oxides of Nitrogen, (NO_x)							
Concentration, mg/l dry	225.00	49.00	120.00	423.00	40.00	—	180.00
Emission Rate, kg/hr		0.016	0.068	0.49	0.012	—	0.18
3. Oxides of Sulfur (SO_2)							
Concentration, mg/l SO_2	2000.00	—	Nil	729.00	Nil	Nil	149.00
Emission Rate, kg/hr		—	Nil	1.17	—	—	0.25
4. Hydrocarbons							
Concentration, mg/l C		5530.00	2800.40	221.00	740.00	561.00	Nil
Emission Rate, kg/hr		0.74	0.56	0.066	0.49	0.095	—
5. Carbon Monoxide (CO)							
Concentration, % vol. dry		5.00	1.7	0.47	1.36	0.86	0.11
6. Odor							
Odor Units/l		777.00		3.00	706.00		0.70
7. Gas Flow							
Temp., ^{0} C		271.40	121.00	665.60	177.80	70.60	620
Rate, l/sec		75.00	112.00	167.00	66.00	93.00	137.4

of the chemical-sewage sludge produced. In this study, the flow of the alum-sewage sludge produced, which was about 1.2 percent of the pilot plant flow, was of the same level as that normally obtained for waste activated sludge. Results of bench-scale studies performed in the course of the study showed that the alum-sewage sludge was difficult to dewater and that chemical conditioning at a cost of $15-$17 per ton dry solids was required to achieve a yield of 4.9-9.8 kg/m^2-hr (1-2 lb/ft^2-hr) with cake solids of 18 percent. The economic analysis, which is discussed in subsequent sections, showed that the sludge treatment accounts for about 59 percent of the capital cost of the chemical clarification system.

The function of the subsequent carbon adsorption step is the removal of residual dissolved organics from the chemical clarification system. Since inert media filtration was not provided, the carbon contactor also served as a deep bed filter for the removal of suspended solids from the clarified effluent feed. Because of the suspended solids load as well as the biological growths produced within the column, daily backwashing was required to relieve the column of excessive headloss and to minimize septicity in the column. Despite the daily backwashing, sulfide generation still occurred in the column. Of the various sulfide control methods evaluated, continuous sodium nitrate addition to the column at a dosage of about 5.4 mg/l N was found to be the most effective. Moreover, the sodium nitrate added to the column enhanced the biological activity within the column resulting in improved overall dissolved organics removal. In comparing the organic removal before and after sodium nitrate addition, it was demonstrated that, indeed, nitrate addition brought about a significant increase in the capacity of the carbon for DCOD removal. While the carbon DCOD removal capacity tends to decrease with repeated thermal regeneration as had been shown from previous study at Pomona (7), results from the current study has demonstrated higher carbon capacity of the regenerated carbon compared to that of virgin carbon. This result may be due to enhanced biological activity within the column brought about by the nitrate addition, rather than a change in the carbon adsorptive property.

A summary of the overall performance of the IPC pilot plant is presented in Table 12. The values shown in the table are the average effluent quality characteristics and removal efficiencies obtained during the entire 27 months of the study. For purposes of comparison, the effluent quality from a 30,280 cu m/day (8 mgd) activated sludge plant treating the same raw sewage is also included in Table 12. The data clearly demonstrate the superiority of the IPC system effluent quality over that of the secondary effluents.

Effect of Copper Waste on IPC System

One of the main advantages of the physical-chemical treatment system over biological secondary treatment processes is the ability of the IPC system to consistently produce good quality effluent even in the presence of toxic industrial wastes. The stability of the IPC system operation was

TABLE 12. SUMMARY OF IPC SYSTEM PERFORMANCE*

Parameters	Raw Sewage	Clarified Effluent	Carbon Effluent	Average Percent Removal			Activated Sludge Plant Effluent
				Chemical Treatment	Carbon Treatment	Overall	
Suspended Solids, mg/l	196	29.3	6.7	85.0	76.3	96.6	11.6
Turbidity, JTU		22.9	6.3		72.5		7.7
TOD, mg/l	321	95.8	19.3	70.2	79.9	94.0	38.5
COD, mg/l	471.4	48.6	13.5	7.6	72.2	72.7	25.7
BOD$_5$, mg/l		16.2	7.8		78.5		8.0
Total Phosphate, mg/l P	11.1	1.3	0.90	88.3	30.8	91.9	
Nitrate, mg/l N		0.90	1.3				
Color		20.0	7.8		61.0		33.1
pH	7.7	6.8	5.8				

* Average alum dosage = 25 mg/l Al (275 mg/l alum). Average polymer dosage = 0.3 mg/l Calgon WT-3000.

indeed demonstrated during a one-week period when the Pomona activated sludge plant suffered a severe upset caused by a discharge of copper-bearing wastes. The measured copper concentration in the sewage for the 24-hour period from March 13 to March 14, 1972 was 1.2 mg/l Cu. As expected, the activated sludge plant effluent quality deteriorated, as shown by the high levels of suspended solids and COD, whereas, the IPC effluent quality remained essentially unchanged. Figures 34 through 36 clearly demonstrate the superiority of the IPC system performance over that of the activated sludge process especially during periods when copper wastes were present in the incoming raw sewage.

Metals and Miscellaneous Analyses

Periodically during the course of the study, determination of heavy metals and other chemical analyses were performed on the various waste streams on the IPC system. The results of the metal analyses are presented in Table 13. The data indicate that the metal constituents in the carbon effluent were generally low except for iron and zinc which were significantly higher than those present in the chemically clarified effluent. The agressive environment within the carbon column produced by anaerobic conditions, and the presence of organic sulfides and sulfate-reducing bacteria could have contributed to the process of corrosion. Although the interior of the column was initially coated with coal tar epoxy to inhibit corrosion, there could have been some areas which were not properly coated. In fact, when the column was taken off stream for repairs as discussed previously, (Dec. 1972 - Jan. 1973), there were some parts where the coating separated from the column exposing the metal. This exposed metal was covered with heavy brush-on coat of bituminstic coal tar epoxy before the column operation was resumed. In subsequent periods, the concentrations of zinc and iron were still high indicating active corrosion taking place within the column. The extent of corrosion within the column became evident in the last two months of the study when leaks occurred at several places along the carbon column.

Table 14 presents the results of mineral analyses and other determinations. As indicated in the table, the alkalinity, sulfate, total dissolved solids and conductivity of the wastewater showed significant changes in passing through the various stages of the IPC system. As a result of the alum addition, sulfate was added to the wastewater in an amount equivalent to 5.2 mg/l SO_4 per mg/l Al added compared to the theoretical value of 5.4. Other soluble wastewater components, however, such as phosphate and alkalinity were reduced in concentration, the net effect of which was a slight increase in the clarified effluent total dissolved solids (TDS) concentration. A slight increase in the TDS concentration occurred in the carbon effluent as a result of sodium nitrate addition to the column for sulfide control. As indicated in the table, the conductivity of the effluents also increased correspondingly.

Although a high alum dosage ranging from 22-25 mg/l Al (242-275 mg/l

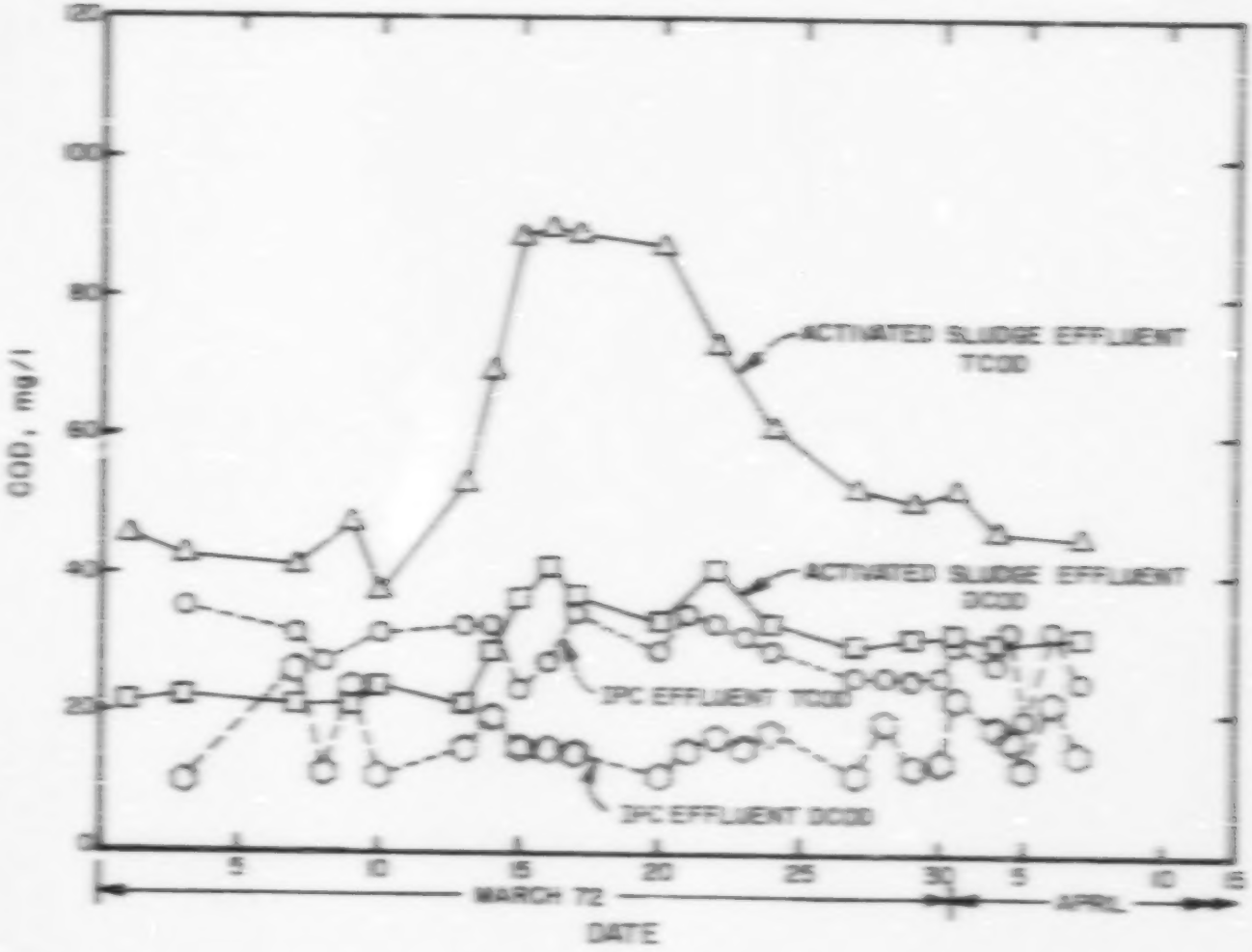

Figure 34. Effect of copper waste on the COD removal

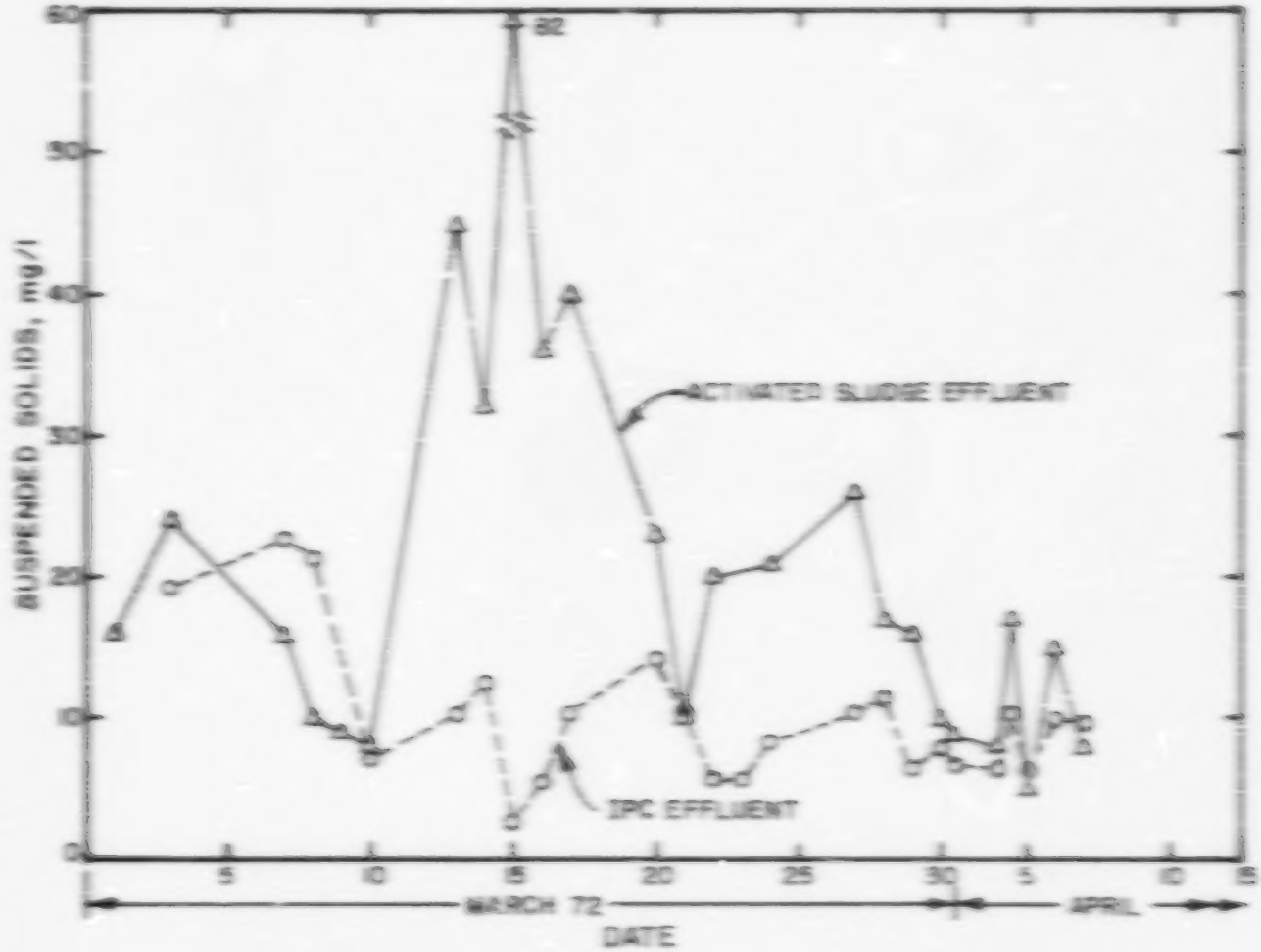

Figure 35. Effect of copper waste on suspended solids removal.

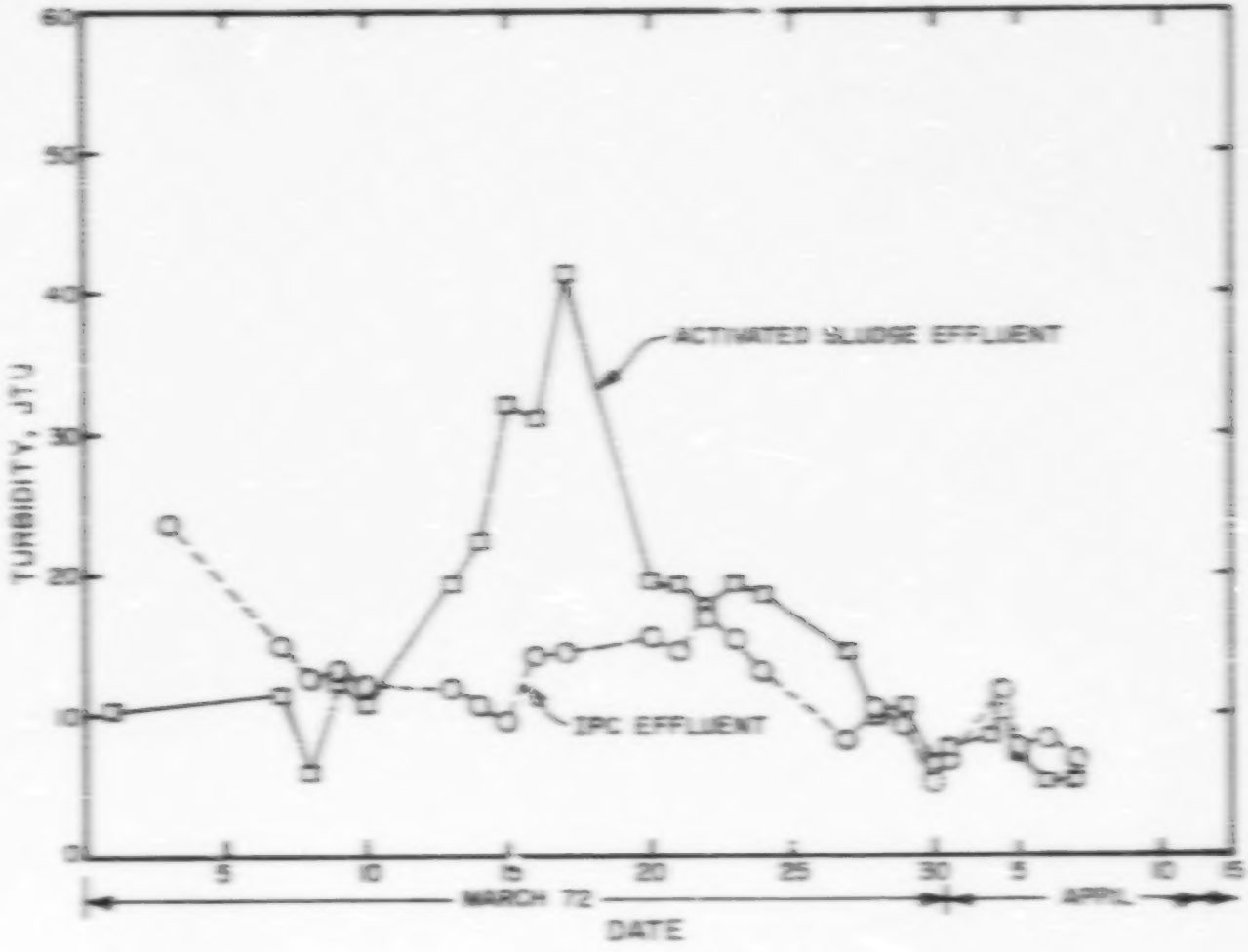

Figure 36. Effect of copper waste on turbidity removal.

TABLE 13. HEAVY METAL ANALYSES

Constituents (ug/l)	Raw Sewage	Clarified Effluent	Carbon Effluent	Average Removal, %	
				Chemical Treatment	Carbon Column
Aluminum	70.0	336.0	50.0	--	85.1
Arsenic	22.0	9.1	7.0	58.6	23.1
Boron	720.0	429.0	610.0	40.4	--
Cadmium	4.0	2.9	2.6	27.5	10.3
Chromium (Hex.)	45.0	36.0	2.3	20.0	93.6
Chromium (Total)	238.0	110.0	25.0	53.8	77.3
Copper	830.00	275.0	71.0	66.9	74.2
Cyanide	26.0	19.1	11.5	23.6	39.8
Fluoride	890.0	303.0	290.0	66.0	4.3
Iron	880.0	228.0	928.0	74.1	--
Lead	185.0	366.0	28.5	80.2	22.1
Manganese	16.0	17.5	20.0	--	--
Mercury	0.8	0.3	0	66.7	100.0
Nickel	190.0	182.0	105.0	4.2	42.3
Silver	4.2	1.8	6.7	57.1	--
Zinc	217.0	257.0	587.0	--	--

TABLE 14. MINERAL AND MISCELLANEOUS ANALYSES

Constituents	Raw Sewage	Clarified Effluent	Carbon Effluent
Alkalinity, mg/l $CaCO_3$	217.00	130.00	169.00
Calcium, mg/l Ca	51.30	52.8	52.4
Chloride, mg/l Cl	104.40	105.40	96.20
Magnesium, mg/l Mg	10.90	11.20	11.00
Nitrate, mg/l N		0.30	1.32
Potassium, mg/l K	10.50	10.80	11.40
Sodium, mg/l Na	100.00	101.00	113.00
Sulfate, mg/l SO_4	95.00	225.00	219.00
MBAS, mg/l	1.96	2.42	0.43
Phenols, mg/l phenol	0.17	0.055	0.005
Conductivity, umho/cm^2		1046.00	1089.00
Total dissolved solids, mg/l	573.00	618.00	627.00
pH	7.68	6.75	6.80

alum) was used in the chemical clarification of the raw sewage, the clarified effluent and carbon effluent contained only 0.31 and 0.05 mg/l Al, respectively. The alum floc in the clarified effluent was effectively filtered out in the carbon column. While most of the trapped floc was removed from the carbon column during the routine backwash operation, invariably some floc adhered tenaciously to the carbon granules.

In an effort to determine the fate of various metals present in the chemically clarified effluent in passing through the carbon column, samples of virgin carbon, spent carbon and quench water were collected during the first carbon regeneration. These samples were analyzed for various metal constituents at the Municipal Environment Research Laboratory of the U.S. EPA in Cincinnati, Ohio. The summary of the test results are presented in Table 15. In evaluating the data from this table, the following general observations can be drawn:

(1) The spent carbon contained considerably larger concentrations of Cd, Cr, Cu, Ni and Zn than were present in the virgin carbon. Analyses of spent carbon taken at various depths of the column showed the amount of Cd, Cr, Cu and Zn were highest at the top 30.5 cm (12 in.) of the carbon bed with the concentration of nickel about evenly distributed throughout the bed. The concentrations of Hg, Ti, Be, As and Sr in the spent carbon were lower than that in the virgin carbon.

(2) The concentrations of Zn, Cr, Cu and Ni in the regenerated carbon were much higher than those of virgin carbon. In comparing the metal contents of the spent carbon composite samples with those of the 12-hr regenerated carbon composite samples, it is apparent that a high loss of Cd and small losses of Zn, Cr, Cu, As, Fe and Pb occurred on regeneration.

(3) The baghouse dust contained considerably higher levels of Ca, Cd, Cu, Cr, Al, Fe, Sr, Sn, Pb, Ni, and Zn than virgin carbon.

(4) The metal constitutents in the quench water were found generally near background levels.

(5) Unlike the other metals, Cd was almost completely stripped from the carbon during regeneration and ended up in the baghouse.

The changes in the various forms of nitrogen during chemical treatment and subsequent carbon adsorption are presented in Table 16. The ammonia concentration increased from 14.5 mg/l N in the raw sewage to 21.2 mg/l N after chemical clarification and remained essentially unchanged in passing through the carbon column. However, the organic nitrogen concentration showed a significant drop from 14.7 in the raw sewage to 0.3 mg/l N in the clarified effluent and to a level of 2.1 mg/l N after carbon adsorption. The nitrate concentration in the

TABLE 15. HEAVY METAL CONSTITUENTS OF QUENCH WATER AND CARBON SAMPLES

Metal	Virgin Filtrasorb 300	Spent Carbon Composite	Avg. of 4-12 hr Composites of Regenerated Carbon	Avg. of 4-12 hr Composites of Quench Water *	Steinhaus Test
Hg	1.92	0.36	0.45	<0.0007	<.0024
Se	<0.96	<.96	9.84	<0.04	0.96
Sb	<7.20	<7.20	<7.20	<0.40	16.80
Sn	<48.00	72.00	<48.00	<2.00	192.00
Co	<4.80	14.40	24.00	<0.20	40.80
Tl	<24.00	<24.00	<24.00	<1.00	24.00
Mo	<12.00	<12.00	<12.00	<0.50	72.00
Ti	240.00	96.00	276.00	<1.00	168.00
V	24.00	24.00	24.00	<1.00	168.00
Be	2.40	<2.40	<2.40	<0.10	2.40
Bi	<24.00	<24.00	<24.00	<1.00	<24.00
Zn	1.20	132.00	102.00	1.40	7080.00
Cr	7.20	658.00	559.60	<0.10	4680.00
Pb	16.80	19.20	13.80	<0.56	3360.00
Ni	72.00	696.00	935.00	<0.50	1032.00
Mn	26.40	1.20	30.60	<0.50	48.60
Cu	<1.20	[illegible].00	286.30	0.65	12,000.00
Ba	50.40	76.80	79.70	<0.50	372.00
Cd	1.20	26.40	<1.20	0.42	446.00
As	108.00	57.60	49.30	<1.00	74.40
Fe	577.00	1200.00	972.00	0.32	10,320.00
Al	1536.00	1405.00	3762.00	<1.00	17,256.00
Sr	72.00	38.40	80.40	0.32	192.00
Ca	397.00	3720.00	4632.00	44.70	17,256.00

* Concentration expressed in mg/l. Concentration for all other samples in mg/kg carbon.

TABLE 14. NITROGEN REMOVAL IN THE IPC SYSTEM

Nitrogen Forms (mg/l)	Raw Sewage	Clarified Effluent	Carbon Effluent	Percent Removal		
				Chemical Treatment	Carbon Treatment	Overall
Organic N	14.7	6.3	2.1	57.1	66.7	85.7
NH_3-N	14.5	21.2	21.3	—	—	—
NO_2-N	0.8	0.4	0.2	50.0	50.0	75.0
NO_3-N	2.6	0.9	1.3(*)	65.4	78.4 (**)	—
Total N	32.6	28.8	24.9	11.7	27.2 (**)	

* Sodium nitrate fed to carbon column = 4.5 - 5.8 mg/l N
** Based on an average sodium nitrate fed to column = 5.4 mg/l N

carbon effluent averaged 1.3 mg/l N which was slightly higher than that of the clarified effluent. The nitrate, which was added to the carbon column at dosages from 4.5 - 5.8 mg/l N for sulfide control was completely reduced presumably by biological denitrification in the carbon column. The significant increase of the ammonia level in the clarified effluent was probably due to the biological oxidation of the organic nitrogen in the raw sewage and/or in the alum-sewage sludge.

SECTION 6

ECONOMIC ANALYSIS

For convenience in the discussion of the economic analysis, the estimated treatment cost for the IPC system is subdivided into three parts, namely, chemical treatment costs, carbon treatment costs and total IPC system costs. The economic analysis is based on the treatment of Pomona wastewater for an average design flow of 0.44 m^3/sec (10 mgd) and a peak design flow of 0.61 m^3/sec (14 mgd). The process design parameters for sizing the various treatment units are presented in Table 17. The assumed unit costs for chemicals and other direct costs for estimating the operation and maintenance (O/M) costs are shown in Table 18. Figure 17 presents the IPC system flowsheet, showing the various treatment components employed.

In the preparation of the economic analysis, various published reports were consulted, particularly references (13,14) for the chemical treatment system and reference (6) for the carbon contacting system. The capital costs obtained from literature were adjusted to reflect the price levels of March 1975, with an EPA sewage treatment plant construction cost index of 232.1.

CHEMICAL TREATMENT COSTS

Table 19 presents a summary of the chemical treatment costs for a 0.44 m^3/sec (10 mgd) plant. The estimated capital costs of the various treatment components include allowance for instrumentation, pipings, appurtenances and buildings. In addition, an allowance of 20 percent of the total capital costs is included for engineering, legal and administrative costs. The preliminary treatment costs include the costs for bar screening, comminution, grit removal and flow measurement.

The costs in Table 19 show that about 59 percent of the total capital costs is associated with the treatment and disposal of the alum-sewage sludge produced in the chemical coagulation-sedimentation system. Of the total chemical treatment cost of 5.29 ¢/m^3 (19.81 ¢/1000 gallons), 67 percent represents operation and maintenance (O/M) and only 33 percent for capital amortization. Moreover, about 67 percent of the O/M costs is associated with the cost of alum and polymer used in the chemical clarification of the raw sewage.

TABLE 17. IPC SYSTEM DESIGN DATA

CHEMICAL TREATMENT SYSTEM	
1. Flocculation:	
Detention Time, minutes	45.0
Chemical Dosage	
Alum, mg/l Al	22.0
Polymer, mg/l	0.25
2. Sedimentation:	
Detention Time, hours	1.3
Overflow Rate, cu m/day/m^2	36.6
Underflow, % of plant flow	1.25
Underflow solids, % by weight	2.0
3. Gravity Thickening:	
Solids Loading, kg/day-m^2	58.3
Underflow solids, % by weight	4.0
4. Vacuum Filtration:	
Yield, kg/hr-m^2	9.8
Cake solids	18.0
5. Sludge Incineration:	
Solids Loading, kg/hr-m^2	9.8
CARBON TREATMENT SYSTEM	
1. Carbon Contacting (8 x 30 mesh carbon)	
Empty-bed contact time	25.0
Hydraulic surface loading, l/sec/m^2	2.7
Backwash volume , % of plant flow	5.0
Sodium Nitrate Dosage, mg/l N	5.5
Carbon Dosage, kg/m^3	0.03
Carbon Regeneration loss, %	5.0

TABLE 13. UNIT COSTS FOR OPERATION AND MAINTENANCE ESTIMATE

CHEMICALS	
Alum, $/kg Al	1.00
Polymer, $/kg	4.40
Sludge conditioning polymer, $/ton dry solids	15.00
Sodium nitrate, $/kg sodium nitrate	0.16
Granular activated carbon (8 x 30 mesh), $/kg	1.10
OPERATING COSTS	
Power, ¢/KWH	2.0
Fuel, ¢/therm	10.0
Carbon regeneration fuel, KJ/kg	14,000.00
Sludge incineration, $/ton dry solids	5.0
Backwash water, ¢/m³	0.8
Operating labor, 5 at $12,000/yr.	60,000.00
Maintenance labor, 2 at $10,000/yr.	20,000.00
Laboratory personnel, 1 at $14,000/yr.	14,000.00
Maintenance materials, $/yr	
Chemical treatment	20,000.00
Carbon treatment	10,000.00
CAPITAL COSTS	
All equipment costs were amortized at 6% for 25 years.	

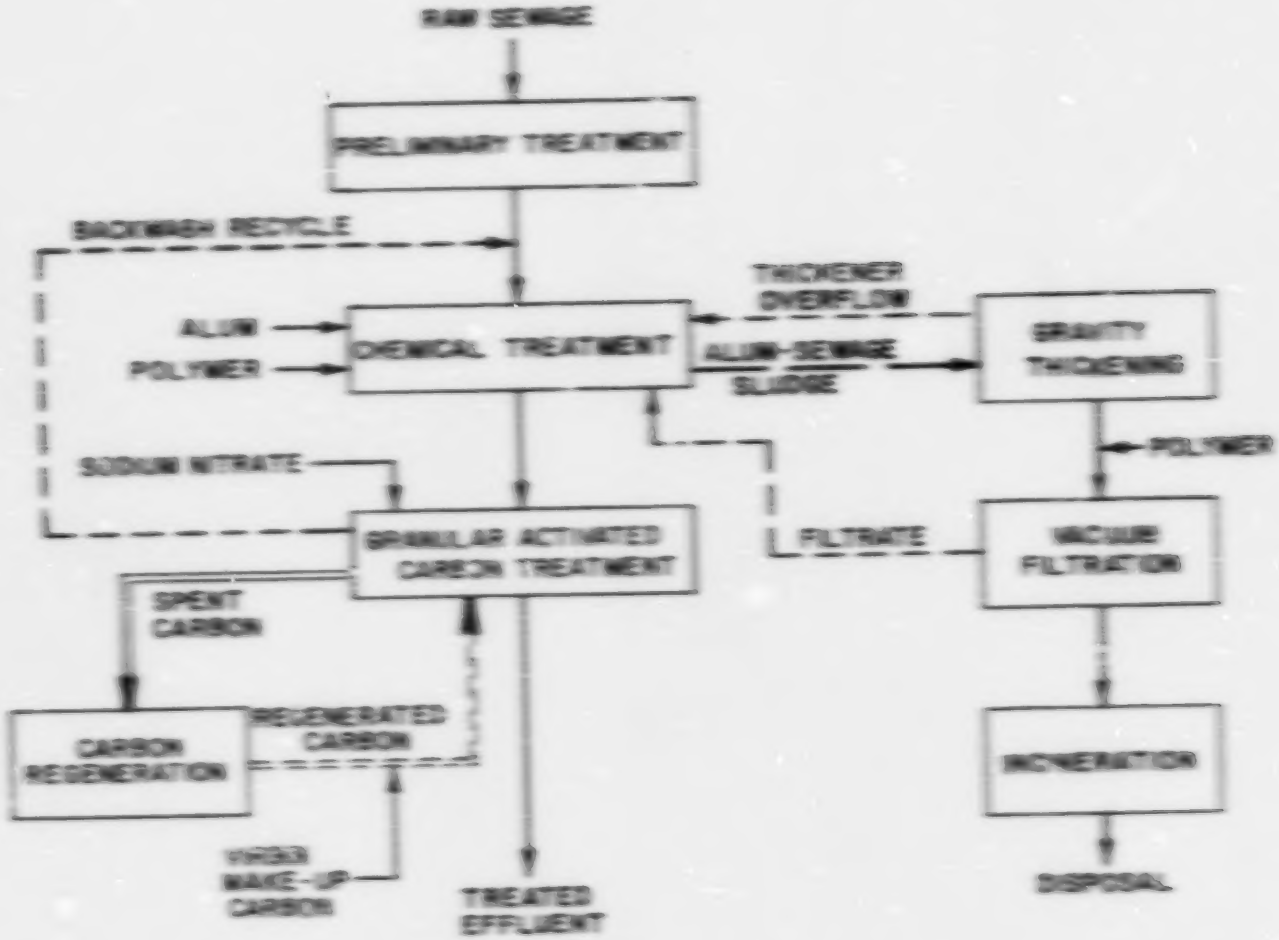

Figure 37. Proposed IPC system-flow sheet.

TABLE 19. ESTIMATED CHEMICAL TREATMENT COST*

CAPITAL COSTS (1000 of $)		
Raw Sewage pumping station	388	
Preliminary Treatment	85	
Coagulation-Sedimentation	568	
Gravity Thickening	94	
Vacuum Filtration	584	
Incineration	812	
total	2,531	
Engineering, legal and administrative costs, (20%)	506	
total capital costs	3,037	
Amortized cost, ¢/m³ ($/1000 gallons)		1.74 (6.50)
OPERATION AND MAINTENANCE COSTS ¢/m³ ($/1000 gallons)		
Treatment Chemicals (alum and polymer)		2.32 (8.86)
Sludge Conditioning Chemical (polymer)		0.42 (1.56)
Power and Fuel		0.28 (1.06)
Operating and maintenance labor		0.34 (1.28)
Maintenance material		0.15 (0.55)
total operating and maintenance cost, ¢/m³ (¢/1000 gallons)		3.55 (13.31)
total treatment cost, ¢/m³ (¢/1000 gallons)		5.29 (19.81)

* Based on EPA sewage treatment plant construction cost index of 232.1 (March 1975) for a 37,850 cu m/day (10 mgd) plant.

CARBON TREATMENT COSTS

The carbon contacting system consists of 10 carbon columns operated in parallel at a design flow of 0.44 m^3/sec (1 mgd) per column. Two carbon storage tanks, each of which has a capacity equal to that of a carbon column, is also provided. One of these storage tanks is initially charged with carbon while the other tank is reserved for spent carbon storage. Thus, the initial carbon charge is equivalent to the effective volume of 11 carbon contactors.

A summary of the estimated carbon treatment costs is presented in Table 20. As indicated in the cost breakdown, the amortized cost represents about 2.04 ¢/m^3 (7.62 ¢/1000 gallons). The costs of sulfide control in the carbon column accounts for 37.5 percent of the total O/M costs. The operating and maintenance labor costs of 0.34 ¢/m^3 (1.28 ¢/1000 gallons), is assumed to be one-half of that of the complete IPC system.

IPC SYSTEM COST

In Table 21 is shown the complete cost breakdown of the IPC system. The total treatment cost to produce carbon treated effluent with characteristics similar to that presented in Table 8 from 0.44 m^3/sec (10 mgd) of raw sewage is estimated at 8.69 ¢/m^3 (32.57 ¢/1000 gallons). The effluent quality from the IPC system would be about equal to or slightly better than that obtained from a secondary biological treatment system for all the parameters evaluated. Moreover, the IPC system has the added advantage of not only providing stable effluent quality but also effluent with total phosphate concentration of 0.9 to 1 mg/l P.

The cost data in Table 21 show that the chemical treatment system cost, which includes the cost for the treatment and disposal of the alum-sewage sludge, represents about 61 percent of the total IPC system process costs. If regeneration facilities were not required, the total treatment cost is reduced to 7.92 ¢/m^3 (29.68 ¢/1000 gallons). This 9 percent cost reduction is important especially in small plants where the regeneration cost represents a significant portion of the overall cost.

TABLE 20. ESTIMATED GRANULAR ACTIVATED CARBON TREATMENT COSTS*

CAPITAL COSTS (1000 of $)		
Influent Pumping	219	
Initial Carbon Charge	331	
Carbon Contacting System	1,966	
Carbon Regeneration System	450	
Total	2,966	
Engineering, legal and administrative costs (20%)	593	
Total capital cost	3,559	
Amortized cost, ¢/m³ (¢/1000 gallons)	2.04	(7.62)
OPERATING AND MAINTENANCE COSTS ¢/m³ (¢/1000 gallons)		
Carbon make-up	0.16	(.62)
Backwash water	0.04	(.15)
Power and fuel	0.24	(.89)
Sulfide control (sodium nitrate)	0.51	(1.93)
Operating and maintenance labor	0.34	(1.28)
Maintenance material	0.07	(.27)
Total operating and maintenance cost, ¢/m³ (¢/1000 gallons)	1.36	(5.14)
Total treatment cost, ¢/m³ (¢/1000 gallons)	3.40	(12.76)

* Based on EPA sewage treatment plant construction cost index of 232.1 (March 1975) for a 37,850 cu m/day (10 mgd) plant.

TABLE 21. ESTIMATED IPC SYSTEM COSTS*

CAPITAL COSTS (1000 of $)		
Chemical Treatment System	3,037	
Carbon Treatment System	3,559	
Total Capital Cost	6,596	
Amortized Cost, ¢/m³ (¢/1000 gallons)		3.77 (14.13)
OPERATING AND MAINTENANCE COSTS ¢/m³ (¢/1000 gallons)		
Chemical Treatment System		3.55 (13.31)
Carbon Treatment System		1.36 (5.14)
Total operating and maintenance cost		4.91 (18.45)
TOTAL IPC SYSTEM COSTS ¢/m³ (¢/1000 gallons)		
Chemical Treatment System		5.79 (19.01)
Carbon Treatment System		3.40 (12.78)
Total Treatment Cost		8.69 (32.79)

* Based on EPA sewage treatment plant construction cost index of 232.1 (March 1975) for a 37,850 cu m/day (10 mgd) plant.

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